Energy Efficiency

A Guide to Current & Emerging Technologies

Volume 1 Buildings & Transportation

Centre for Advanced Engineering

University of Canterbury, Christchurch, New Zealand

This pdf was created from the original Pagemaker files in June 2011. With the exception of the five section break pages (where a plain background is substituted for the now-lost graphic background), this pdf version is an exact replica of the original publication.

Energy Efficiency

A Guide to Current and Emerging Technologies

VOLUME 1

Buildings and Transportation

Centre for Advanced Engineering
University of Canterbury Christchurch New Zealand

Energy Efficiency: A Guide to Current and Emerging Technologies
is published in two volumes:

Volume 1: Buildings and Transportation ISBN 0-908993-06-4

Volume 2: Industry and Primary Production ISBN 0-908993-07-2

ISBN 0-908993-06-4

First printing, April 1996

Printing

Print City, Christchurch

Cover Design

Ken Hudson Graphics, Christchurch

The graphic artwork on the front cover was adapted from a kinetic sculpture by Len Lye and has been chosen to symbolise energy. It is entitled *Blade 1972 - 1976* and is described as: "Spring steel blade, cork ball, motor and control, formica and wood base. Height 2856 mm, width 1800 mm, depth 1800 mm. A vibrating ribbon of steel erratically pounds away at a cork ball. Lye described this work as a 'violent, vibrant, rotating affair.' Intended to stand anything up to 100 feet high, it was to reflect light 'like an Aztec monument to the sun'". Reproduced courtesy of the Len Lye Foundation.

Editorial Services and Book Design

Charles Hendtlass and Janine Griffin, Centre for Advanced Engineering

Centre for Advanced Engineering

Establishment

The Centre for Advanced Engineering was founded in May 1987 to mark the centenary of the School of Engineering at the University of Canterbury. It was established by means of an appeal fund launched in conjunction with the centennial celebrations. To date approximately $2 million has been raised, contributed by 150 corporate donors and 750 individual donors. The earnings from this capital sum assist in funding the activities of the Centre.

Objective

The objective of the Centre is to enhance engineering knowledge within New Zealand in identified areas judged to be of national importance and to engage in technology transfer of the latest research information available from overseas. The Centre is not concerned with basic engineering research but with the application of research findings to engineering problems.

The objective is achieved for each major project undertaken by bringing together a selected group of practising and research engineers and experts in the particular field from both New Zealand and overseas to:

- consolidate existing knowledge;
- study advanced techniques;
- develop approaches to particular problems in engineering and technology;
- promote excellence in engineering; and
- disseminate findings through documentation and public seminars.

A unique forum for co-operation among industry, the engineering profession and university research engineers is thus provided.

Function

The Centre is managed by a Board of Directors comprising representatives from industry, the engineering profession and the University of Canterbury. Chairman of the Board is Mr Gavin Cormack of Auckland. The Board selects the title for each project undertaken by the Centre and approves the level of funding. A Steering Committee is then appointed, initially to carry out detailed planning for the project and then to provide overall direction. The Steering Committee appoints Task Group Leaders and a Project Manager.

Detailed work on the project is carried out on a voluntary basis by the members appointed to each Task Group. The Centre arranges to bring to New Zealand, at the appropriate time, several Visiting Fellows to work with members of the Task Groups, bringing to the project the latest available information from overseas.

The Centre also undertakes a variety of smaller projects and produces publications on engineering subjects of current concern, and arranges lectures and seminars on appropriate topics as the occasion arises.

Contact:

Centre for Advanced Engineering
University of Canterbury
Private Bag 4800
Christchurch
New Zealand

Street Address:

39 Creyke Road
Christchurch 4

Telephone: +64-3-364-2478
Fax: +64-3-364-2069
e-mail: j.blakeley@cae.canterbury.ac.nz

Executive Director: John P Blakeley
Projects Director: John L Lumsden

Contents of Volume 1

Acknowledgements

The Centre for Advanced Engineering greatly appreciates the financial contributions received from the following organisations towards the cost of this project.

Principal Sponsors

ECNZ

Electricity Corporation of New Zealand Limited

EECA
Energy Efficiency and Conservation Authority

Energy Efficiency and Conservation Authority

NATURAL GAS CORPORATION

Natural Gas Corporation Limited

Supporters

Canterbury Regional Council
CentralPower Limited
Dunedin Electricity Limited
Hawke's Bay Power
Hutt City Council
Manawatu-Wanganui Regional Council
Mercury Energy
Methanex New Zealand Limited
NZ Refining Co Limited
Power New Zealand Limited
Powerco Limited
PowerDirect
Rotorua Electricity Limited
Tasman Energy Limited
The British Council
Wairarapa Electricity Limited
WEL Energy Group Limited
Wellington Regional Council

Technical Contributions

The project has been notable for the wide support from individuals and organisations. Most of the input by the Task Groups and Steering Committee was given on a voluntary basis, representing an essential and much appreciated contribution to the project.

Glossary of Terms

ALF	Annual Loss Factor procedure used to assess insulation requirements for homes
BEMS	Computerised Building Energy Management System
BIA	Building Industry Authority
BRANZ	Building Research Association of New Zealand
CAE	Centre for Advanced Engineering
CAFE	Corporate Average Fuel Economy standard. The sales weighted fuel economy of vehicles sold by each US manufacturer/importer
CBD	Central Business District
CFC	Chlorofluorcarbons
CFLs	Compact fluorescent lamps
CH_4	Methane
CNG	Compressed Natural Gas (mainly methane)
CO_2	Carbon Dioxide
CO	Carbon Monoxide
COP	Coefficient of Performance. The ratio of useful energy output to the energy input for energy conversion devices such as heat pumps
DC/AC	Direct Current/Alternating Current
EDA	Electrical Development Association of New Zealand Inc
EECA	Energy Efficiency and Conservation Authority
Embodied energy	Energy used in the construction of a product such as a car, or infrastructure such as a motorway
Energy Star	US Environmental Protection Agency PC efficiency programme
EVs	Electric Vehicles
FCCC	Framework Convention on Climate Change international treaty
Feebate	A scheme where a part of the purchase price of efficient cars, appliances etc. is refunded out of fees on inefficient products
GJ	Gigajoule (10^9 joules)
GVW	Gross Vehicle Weight
HP	Horsepower, measure of power (approximately 750 W)
HVAC	Heating Ventilation and Air Conditioning systems in commercial buildings
Hydronic heating	Systems using hot water for space heating
IEA	International Energy Agency
IGU	Insulating Glass Unit e.g. double glazing)

IRR	Internal Rate of Return in economic analysis
Joule	Unit of energy
K	Degrees Kelvin, measure of temperature above absolute zero
kWh	Kilowatt-hour. A unit of energy (3.6 x 10^3 joules)
LFTB	Liquid Fuels Trust Board (disestablished 1987)
LPG	Liquified Petroleum Gas. A propane/butane mixture
LRT	Light rail passenger transit system
Lux	Measure of visible light intensity
MEPS	Minimum energy performance standards for household appliances, office equipment, etc.
Modes (transport)	Ways of moving people or goods (e.g. road, rail, cars and buses)
MJ	Megajoule (10^6 joules)
M&T	Monitoring and Targeting systems for energy management
NLTS	National Land Transport Study. A New Zealand government initiative
NO_X	A family of gases formed by the oxidation of nitrogen
NZERDC	New Zealand Energy Research and Development Committee (disestablished 1988)
NZS	New Zealand Standard
OECD	Organisation for Economic Cooperation and Development
Pa	Pascal, a measure of pressure
PC	Personal Computer
PC-ALF	PC computer program to calculate heat balance for buildings (ALF = Annual Loss Factor)
PCBs	Polychlorinated biphenyls
PJ	Petajoule (10^{15} joule)
p-km	Passenger kilometre. A unit of passenger transport
R&D	Research and Development
RPM	Revolutions per Minute
R-value	Insulation effectiveness. Temperature differential to create 1W heat flow through 1 m^2 of building material (units m^2.°C/W)
Thermal mass	Building element that absorbs and releases significant amounts of heat
tonne-km	tonne kilometre. A unit of freight movement
Trombe wall	external glazed thermal mass wall for passive solar gain
UNEP	United Nations Environment Programme
UV	Ultraviolet. Part of the light spectrum
U-value	Inverse of R-value. The heat loss through a material as a result of a temperature differential (W/m^2.°C)
Watermark	EDA electric hot water cylinder labelling scheme
Watt(W)	Measure of power (one joule per second)

General Introduction and Overview

Contents of General Introduction and Overview

General Introduction and Overview

Objectives

The arguments in favour of using energy more efficiently are compelling. Such programmes increase efficiency, reduce energy costs, improve air quality and conserve natural resources and allow longer lead times for the development of new electricity generating facilities. Despite this, the uptake of energy efficient technologies has been slow in this country, especially compared with Europe and North America.

There are a number of reasons for this, and the temperate climate and the lower price of energy in New Zealand, particularly for electricity and gas, are often cited as major factors. However, there is also considered to be a general lack of understanding of the many developments in energy efficient technologies that have occurred in recent years. Without this knowledge and an appreciation of the long-term savings and life-cycle benefits that can be derived, consumers are less likely to take energy efficiency into consideration when purchasing a product. This argument applies whether or not the product is a domestic appliance, a house or an industrial process. Energy prices may rise in the future, but, on its own, without providing information on possible energy efficient options, this is likely to have only a limited impact.

Having identified energy efficiency as a matter of national concern, the Centre for Advanced Engineering at the University of Canterbury, decided to adopt this as the topic of its fourth major project.

For the purposes of the project, energy efficiency was defined as the provision of energy services at lower total economic, environmental and social costs. The focus of this project was on energy efficient technologies that are available but not widely used in New Zealand, and also on emerging technologies that are considered likely to prove practical for use in New Zealand over the next decade. Technology in this sense was taken to include changes in management practices and planning, as well as improvements in structures, plant, controls and infrastructure.

Although the emphasis is on New Zealand experience, the technologies discussed have world-wide application.

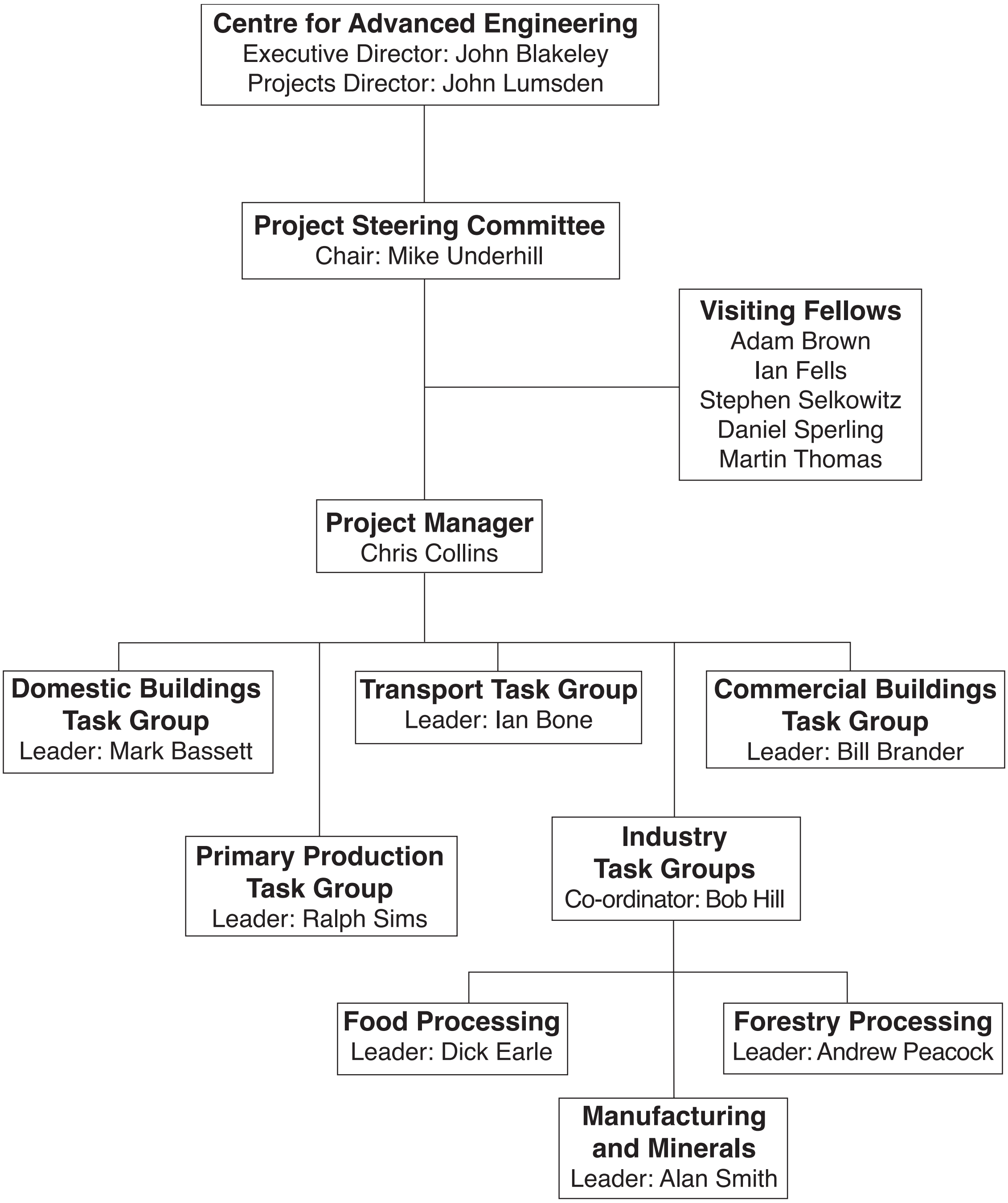
Structure of the Project

A steering committee comprising a number of leading people involved in energy efficiency from a range of sectors was established by the Centre for Advanced Engineering in May 1992. The following seven task groups were subsequently formed, representing the major sectors of the New Zealand economy:

- Domestic Buildings;
- Commercial and Institutional Buildings;
- Transport;
- Primary Production;
- Forestry Processing;
- Food Processing; and
- Manufacturing and Minerals.

During 1993, the task groups prepared reports for discussion at a project workshop, which was held in February 1994. Five international experts in different fields of energy efficiency relevant to the task group work were appointed to the project as Visiting Fellows and each participated in the workshop, which proved to be a highlight of the project and provided a forum for a very active interchange of ideas and opinions.

The following chart illustrates the organisation of the project.



Following the project workshop, the discussion documents were edited and amended to include the latest available technologies, and the work is presented in two volumes:

- Volume 1 "Buildings and Transportation" covers the work of the first three task groups in the above list.
- Volume 2 "Industry and Primary Production" cover the work of the remaining four task groups.

Summaries of the highlights from each of the task group reports are included in this General Introduction together with an overview of energy efficiency in New Zealand.

Project Steering Committee

Mr Michael Underhill, Energy Direct (Chairman)

Mr John Allard, Wellington Regional Council

Dr George Baird, Victoria University

Mr John Blakeley, Centre for Advanced Engineering

Mr Christophor Collins, Eden Resources

Mr Stephen Drew, ECNZ Marketing

Mr Murray Ellis, Dialogue Consultants Limited

Ms Ros Gibson, Design Power NZ Limited

Dr Garth Harris, Garth Harris Energy Consultant

Mr Bob Hill, Carter Holt Harvey Limited

Mr John Lumsden, Centre for Advanced Engineering

Ms Molly Melhuish, Power for Our Future

Dr Eric Palmer, Gas Association of New Zealand

Mr Frank Pool, EECA

Dr Wayne Sharman, BRANZ

Mr Peter Sutton, Consumers Institute

Dr Rob Whitney, Coal Research Association of New Zealand

Visiting Fellows

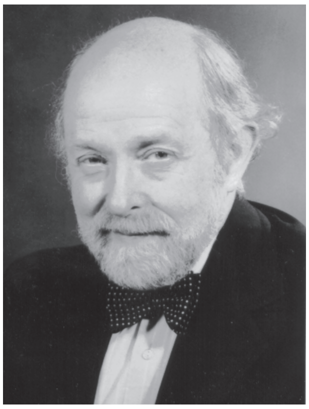
Dr Adam Brown

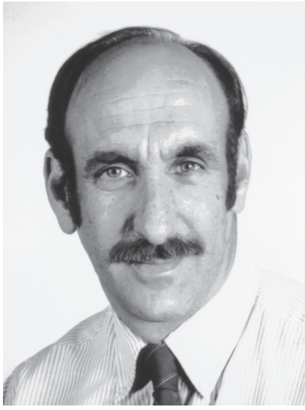
Adam Brown is Manager of Renewable Energy at the Energy Technology and Support Unit, Harwell, UK. He is responsible for the management of the Renewable Energy Programme, which is funded by the UK Department of Trade and Industry.

Dr Brown has wide experience working with industry and government to develop programmes that lead to the most effective use of energy resources. He has managed UK programmes concerned with energy derived from waste, biofuels and solar energy and the Energy Efficiency Demonstration Projects Scheme.

Professor Ian Fells

Ian Fells is Professor of Energy Conversion at the University of Newcastle-upon-Tyne, UK. He is well known in Britain for his work on energy and the environment and has made over 400 radio and television programmes. He is a science advisor to the World Energy Council and has been a special advisor to the House of Lords and House of Commons select committees on energy and environment. In 1979, he was elected a Fellow of the Royal Academy of Engineering.



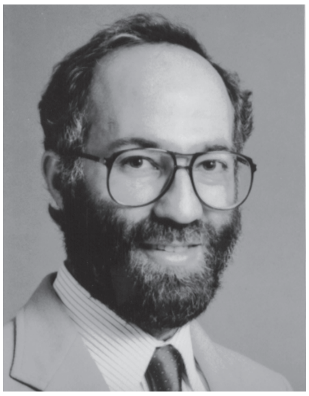


Mr Stephen Selkowitz

Stephen Selkowitz is Program Leader of the Building Technologies Program in the Center for Building Science at Lawrence Berkeley Laboratory (University of California). He is responsible for the Center's Lighting Research, Simulation Research and Windows and Daylighting groups.

Mr Selkowitz is a member of the editorial board of *Energy and Buildings,* an international journal of energy research in the built environment. He has received several awards and honours for his work on energy efficiency in buildings.

Professor Daniel Sperling



Daniel Sperling is Professor of Environmental Studies and Civil Engineering and founding Director of the Institute of Transportation Studies at the University of California, Davis.

In 1990, he was named technical manager of the "Assessment of Electric and Natural Gas Vehicles" programme, a three-year programme funded by California industry and government. He is also co-director of a three-year study of "The Future of Motor Vehicles in an Environmentally-constrained World", which is funded by international automotive and oil companies and the US Department of Transportation. He is co-manager of the "Neighborhood Electric Vehicles" programme for CALSTART, a California-based consortium.

Mr Martin Thomas

Martin Thomas is Principal of Sinclair Knight Merz, Consulting Engineers, which specialises in power generation, power transmission and energy utilisation projects. He is a specialist on energy management in industry and has worked on energy-related projects in many countries. He is the founding and present Chairman of the Australian energy sector exporters group, Austenergy, and is involved in exporting Australian expertise in energy technology and industrial energy management, particularly to Southeast Asia.

Mr Thomas has lectured widely on power generation and industrial energy utilisation and is a past president of the Institution of Engineers, Australia.

Energy Efficiency in New Zealand

A common misconception amongst New Zealanders is that hydroelectricity provides most of the nation's energy supply. Not only is this incorrect, but this notion has implications for the promotion of energy efficiency. Hydro provides just over 70% of the electricity supply but only comprises 14% of the primary energy supply, that is the production of raw energy before conversion and losses. Hydro resources make up 19% of the final end-use or consumer energy supplies. Except during infrequent prolonged dry periods when shortages have occurred, many people generally view electricity as plentiful, derived from clean sources and possibly even running to waste if not used. The truth is that a significant proportion of electricity generation is derived from thermal stations using fossil fuels, mostly natural gas, and in a normal year electricity consumption would have to be reduced by 20% before significant spilling from hydro lakes occurred.

Another important point that is not widely appreciated is the importance of energy resources used in transportation. Table 1 provides a simplified summary of New Zealand's energy supplies. Liquid fuels make up 43% of consumer energy. Around 80% of liquid fuels are used for transport with the balance consumed in primary industries or as a heating fuel.

Table 1 also shows that natural gas is the most important primary energy resource to New Zealand. Only a fraction of the supply, about 20%, is used directly as a reticulated gas supply to homes, offices and industry. The balance is used in energy transformations. In round terms, about 70 PJ is used to produce electricity and, until around 1993, 60 PJ was used to produce synthetic petrol. Now, production of synthetic petrol has largely ceased in favour of producing more profitable chemical grade methanol. Natural gas used as petrochemical feedstock, about 30 PJ, is not shown in Table 1. New Zealand exports liquid fuels such as fuel oil and often the bulk of its synfuels production. So, in one sense, the primary energy figure for natural gas may overstate the actual local consumption of this energy resource.

Energy Source	**Primary Energy**	**%**	**Consumer Energy**	**%**
Natural Gas	180 PJ	30%	40 PJ	10%
Liquid Fuels	165 PJ	28%	170 PJ	43%
Geothermal	90 PJ	15%	20 PJ	5%
Hydro Power	80 PJ	14%	75 PJ	19%
Other Electric	NA	-	25 PJ	6%
Coal - Bit/Lig.	50 PJ	8%	45 PJ	11%
Wood/Pulp Waste	25 PJ	4%	25 PJ	6%
TOTALS	590 PJ	99%	400 PJ	100%

Note: Geothermal energy is used to produce approximately 7 PJ of electricity and 13 PJ of heat.

Table 1: Indicative New Zealand energy supply, 1990-95 (Collins, 1995)

After natural gas, liquid fuels are the next most important primary energy source and they represent the main form of consumer energy. New Zealand produces some of its own liquid fuel requirements from the Maui and Waihapa natural gas and condensate fields in Taranaki, and from synthetic petrol produced from Maui and Kapuni gas. As a result of a recent upgrade, the Synfuels plant is able to produce both synthetic petrol and chemical grade methanol, with the production mix being determined by world prices for these commodities. When production is geared towards synthetic petrol, New Zealand is capable of producing 50% of its liquid fuel needs from indigenous sources. The conversion of natural gas to synthetic petrol is one of the reasons for the liquid fuels consumer energy figure being greater than the primary energy figure.

The amount of geothermal energy tapped as a primary energy source gives a misleading picture of its importance. The conversion of geothermal energy to consumer energy, especially the transformation to electricity, is very inefficient. Added together, the heat and power derived from geothermal energy makes up about 5% of the consumer energy total.

The overall picture is one of heavy reliance on non-renewable fossil fuel energy resources, and the Maui natural gas and condensate field in particular. This field is expected to come to the end of its economic life around the year 2010, but more recent examination of the field's estimated reserves suggest that supplies from this source may be exhausted by 2005/6. It will still contain gas at that time and improved technologies may make further extraction feasible. Other gas fields have been discovered, such as the Kupe field, which is only 10% of the size of Maui, and there is some uncertainty about the economics of developing all the finds. Nevertheless, there is some confidence that known fields and new discoveries will be sufficient to provide for the growing demand for reticulated gas supply and a limited amount of further power generation.

Natural gas is a valuable energy resource. It is relatively clean burning and readily controlled. It can be efficiently used for space, water and industrial process heating. It creates the least amount of greenhouse gas emissions of all fossil fuels. The efficient use of natural gas and the electricity and synthetic petrol derived from it is strategically important. Careful use of electricity from hydro resources also reduces the need for natural gas thermal generation. The large consumer demand for liquid transport fuels and the externalities of their use means that this energy source warrants close attention as well.

Energy efficiency can help to conserve and make best use of valuable gas and condensate resources, defer the need for new investment in power generation, reduce the environmental impacts of energy use and provide a range of other national, business and private benefits.

Table 1 also shows the large losses incurred in transforming primary energy to consumer energy, although the ratio is skewed by the inefficient conversion of geothermal energy. If this source is set aside, then the overall ratio of energy conversion and transport/transmission to consumer energy is 75%. The major sources of losses are in thermal electricity generation and synthetic petrol production, where the ratios are less than 50%. While beyond the scope of this publication, means to improve the efficiency of energy conversion should not be overlooked.

Future Energy Trends

Approximately every two years, the Ministry of Commerce publishes energy supply and demand scenarios. These scenarios are based on forecasts of future energy prices, the country's economic performance and the effects of government policies. Some of the key features of the scenarios published in July 1994 are noted below (Commerce, 1994).

Total primary energy demand is expected to increase by over 50% from 1990 to the year 2020, although the relative contribution from different energy sources changes. Liquid fuel increases its share from 29% to 38%, coal doubles its share to 17%, the natural gas component is reduced by two-thirds, and the renewable component increases slightly.

From the 1990 demand base, liquid fuel use is predicted to experience the greatest primary energy growth at over 100% by the year 2020 (Commerce, 1994). Liquid fuel consumer energy will grow by 73% over the same time period. The different changes for primary and consumer energy reflect a shift in the relative proportions of crude oil processed in New Zealand (higher) versus refined products imported into the country (increase, but at a lower rate). The rises are expected to occur in spite of a real price rise of 25% forecast for the period 1990 to 2010 (IEA, 1993). Authoritative price forecasts out to 2020 are not available.

While in recent years New Zealand has been up to 50% self-sufficient in liquid fuels (depending on production of synthetic petrol), by the year 2000 this degree of self-sufficiency is expected to drop to less than 25%. Small changes will also occur in the overall distribution of liquid fuels across the land, air and sea transport sectors. The proportion of diesel oil in the on- and off-road transport fuel mix, for example, will rise, largely due to predicted growth in the forestry sector.

Local coal demand is expected to grow strongly from the year 2000 onwards due to increasing use in power generation as the Maui gas supply decreases. It is assumed that sufficient gas will continue to be available for peak power generation, but that a significant proportion of the increased base load demand will have to be met from coal-fired power stations unless large-scale development of alternative energy technologies occurs. A small amount of coal is currently used at the Huntly Power Station to check that the back up coal facilities are working properly.

Coal use in metals manufacturing and the other industrial sectors, and also the commercial sector, is expected to grow at a moderate rate, around 1% per year. The net effect is a local coal demand 300% greater by the year 2020 than in 1990. Coal exports are also expected to grow so that they represent a similar tonnage to local demand from the year 2005 onwards. While New Zealand's "measured recoverable" coal reserves are vast (an estimated 9300 PJ), it may not be possible to increase production fast enough to satisfy both local and export demand. It is possible that significant growth in North Island demand, in particular, would be increasingly met by imports. Coal prices are expected to remain relatively constant out to 2020.

Natural gas use for energy purposes is expected to peak at 190 PJ by the year 2000 and decline thereafter. It is expected that new gas discoveries will allow the continued supply of natural gas for reticulated uses and peak power generation. Reticulated gas use will grow to around 56 PJ by the year 2000. Gas use in electricity generation is predicted to decline to around 33 PJ by the year 2010 and stay at this level thereafter.

Notwithstanding new discoveries, the price of gas is expected to rise from 2000 onwards. The wholesale price may increase by over 80%, but the effect will probably be slightly countered by a fall in the transmission and distribution charges. The overall result will be a 12% increase in delivered prices by the year 2020. Rising prices may mean that it will no longer be viable to maintain the existing petrochemical plants (Synfuels, methanol and ammonia/urea plants). The rise in gas price will also mean that coal will replace natural gas for baseload power generation.

After liquid fuels, electricity generation is the energy supply likely to experience the fastest growth. Power demand is expected to grow from around 30,000 GWh (108 PJ) at present to around 45,000 GWh (162 PJ) or more by 2020, an annual rate of increase of 1.6%. The extra load will be met by constructing a variety of new power stations — hydro, geothermal, windfarms, natural gas combined cycle, cogeneration plants and coal-fired plant.

By the year 2010, an extra 1500 MW may need to be built and by the year 2020, an extra 2300 MW of capacity may be needed. At a cost of around $1500/kW the capital requirements over the next ten years or so could exceed 2 billion dollars. Furthermore, the image of New Zealand as a country deriving its electricity from renewable sources will not be improved:

- hydro-based share falls from 70% in the 1990s to around 55%, despite the construction of new hydro stations;
- geothermal's capacity increases from 5% to 11% by 2020, but not enough to compensate for the reduced hydro share;
- wind farming becomes established, but by the year 2020 still only contributes 2%; and
- the share of coal rises from almost nil in 2000 to 18% by the year 2020.

The need to build extra power stations will eventually cause an increase in the price of electricity. This is expected to be particularly noticeable from the year 2003 onwards. Wholesale prices are expected to increase from around 5 c/kWh to over 9 c/kWh by 2020. Prices for residential consumers in the year 2020 could exceed 12 c/kWh as a result (a 30% increase over current levels). Industrial and commercial consumers may experience a small drop in prices over the next 10 years due to retail competition, removal of cross-subsidies, etc. By 2020, however, prices will probably be 10% higher in real terms than at present.

Although renewable energy sources (such as hydro, geothermal and biomass) as a proportion of total primary energy may grow slightly from 1990 to 2020, their share of consumer energy is expected to drop from 30% to 23%. This is due to the fact that while geothermal primary energy use doubles, its poor conversion efficiency means it has little impact on consumer energy supplies. Lack of substitution of renewable resources for fossil fuel resources, and increasing use of the latter, mean that carbon dioxide emissions, a global warming concern, rise markedly.

Energy sector carbon dioxide emissions in 1990 were 7 Mt of carbon (25.6 Mt of CO_2). This figure includes the emissions as a result of supplying international transport, such as bunker oil for ships. Emissions are expected to rise from the present level to 11.3 Mt of carbon (41.5 Mt of CO_2) by 2020. This represents a rise of over 60%. The Framework Convention on Climate Change calls for emissions to be stabilised at 1990 levels by the year 2000. With an expected rise in emissions of around 15% by the year 2000, achieving this goal would be impossible for New Zealand unless a net approach to emissions is adopted and the carbon uptake by forests is counted towards meeting convention obligations.

The above scenario is not necessarily an inevitable picture of the future. Greater awareness and commitment to energy efficiency and the advent of new technologies could lead to a more sustainable and prosperous future. An important issue, covered below, is how energy efficient is New Zealand at present, and what is the potential for improvement?

Energy Intensity

Energy efficiency relates to the amount of energy used to provide a service or physical output, such as effective lighting of an office space or the production of a tonne of paper. Due to the enormous diversity of goods and services produced using energy, a single national measure of energy efficiency is impractical.

At a national level, it is possible to measure total energy use and consequently per capita energy consumption. New Zealand's per capita energy use is below the average for OECD countries and almost half that for North America.

Comparisons on an energy per capita basis are really only valid between countries with similar climates, economies and energy resources. The only areas with circumstances remotely similar to those in New Zealand are south-eastern Australia and possibly Chile. Per capita energy use in Australia is slightly higher than in New Zealand, while the Chilean figure is lower. This information is not enough, however, to draw any conclusions on how efficiently New Zealand uses energy.

The aggregate economic value of goods and services, namely GDP, can be determined and used to create an energy performance index. The amount of primary energy used per unit of economic output is called energy intensity. This index has been put forward as a basis for comparing New Zealand's energy use with that of other nations.

From 1960 to 1975, New Zealand's energy intensity was slowly rising. As shown in Figure 1, it was alternately slightly less or slightly more than the OECD average. (The unit "toe" used in Figure 1, stands for tonnes of oil equivalent and is often used in international statistics. It represents a compromise between SI units and US measures. One toe = 41.8 GJ. The monetary values used to calculate energy intensity are United States dollars corrected for inflation to a 1985 base. Shifting exchange rates can affect comparisons of energy intensity between countries.) After 1975, New Zealand's energy intensity continued to increase while the figure for most OECD countries decreased. Between 1979 and 1990 New Zealand's energy intensity increased by 38%. Several factors appear to have contributed to the divergence between the New Zealand and OECD average energy intensity and these were identified in a 1993 report (EECA, 1993).

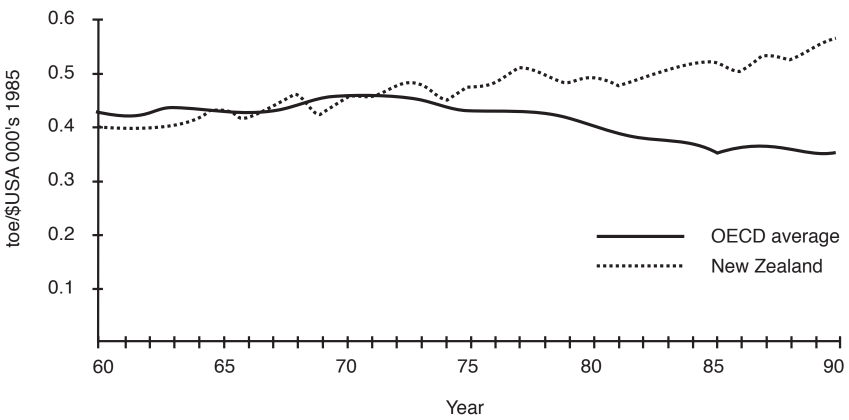


Figure 1: Energy intensity trends (EECA, 1994a)

Most of the OECD nations had largely completed their industrialisation by 1970. They then experienced high economic growth with facilities running close to full capacity, usually their most energy efficient mode. Furthermore, many of the OECD economies became more service industry oriented. This increased the low energy input per economic output component of their economies. Finally, in response to oil shocks and other influences, many OECD nations improved energy efficiency across a range of sectors.

Opposite factors contributed to New Zealand's rise in energy intensity. The development of the major petrochemical projects (synfuels, methanol, ammonia-urea) alone led to a 20% increase in New Zealand's energy intensity from 1979 to 1990. Increased production from energy intensive aluminium, iron and steel plants caused a further 4% increase over this period. Other changes affecting the balance of high and low energy intensive industries took place during the 1980s. Pulp and paper manufacturing, for example, increased its production by around 46% over the 1978-1990 period.

These structural changes in the economy are represented as the sectoral mix effect in Figure 2. This effect is the major cause of the rise in energy intensity (it contributes 27% out of the total change of 38%). During the period 1975-1990, New Zealand's energy input mix changed with fossil fuels, especially natural gas and liquid fuels, forming a greater share of the input per unit of GDP than hydro-generated electricity. Oil, natural gas and coal cannot be converted to useful heat and power as efficiently as hydroelectricity and consequently the total energy input per GDP increased. Overall, though, the change in energy mix is considered a relatively small factor, accounting for 3% of the 38% rise.

Energy intensity can be affected by using energy to substitute for other factors in production such as labour. This factor substitution is additional to any changes as a consequence of changes in the sectoral mix. There appears to have been a strong energy-for-labour substitution trend over the 1971-1984 period, but by 1990 this had been replaced by efforts to improve both energy efficiency and labour use in most sectors. Consequently, the factor substitution effect has made a negligible overall contribution to the changes in New Zealand's energy intensity.

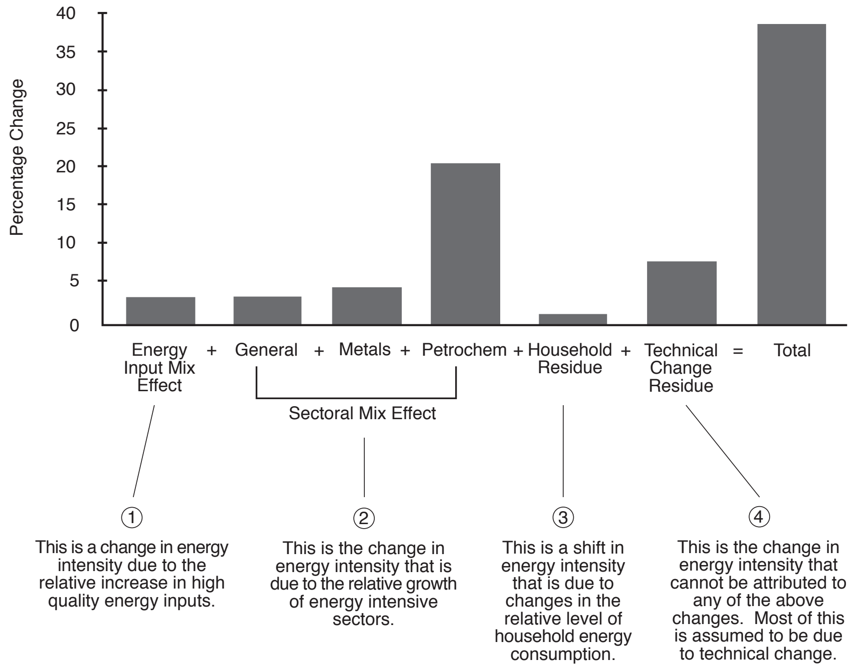


Figure 2: Components of change in New Zealand's energy intensity, 1979-1990 (EECA, 1994a)

There are residual elements that cannot be accounted for by either structural change, substitution factors or shifts in the energy input mix. The household residual is the contribution to the shift in national energy intensity due to changes in the relative level of household energy consumption. An increase in household energy use from 1979 to 1990 is thought to have contributed around 1% of the 38% rise in energy intensity. The second residual, the technical change residual, is the change in energy intensity that cannot be explained by changes in the sectoral mix, the energy input mix, factor substitution or household energy use. This residual accounts for around 7% of the 38% rise in energy intensity.

The technical change residual invites interpretation as a deterioration in energy efficiency, but this may not be justified. The increase in energy intensity associated with this residual is considered to be due to changes in the services sector. A breakdown of the overall residual shows that the residuals for the other sectors were negative, that is they tended to reduce energy intensity. It appears that more energy has been used in the service sector to improve the level of energy services, such as space conditioning and lighting, but this improvement has not created a commensurate increase in the dollar value of outputs. In effect, the service sector has redefined the levels of amenity it expects from energy use. Consequently, it is not possible to interpret the technical residual as a drop in energy efficiency.

Recent data indicates that the upward trend has ceased and consumer energy intensity is declining. It has fallen by around 3% per annum in each of the last two years to 1995. In the year to 31 March 1995, GDP growth was just over 6%, reflecting a sudden increase in economic activity, while consumer energy increased by only 2.6%. Liquid fuel demand growth matched GDP while the demand for other fuels either fell or rose less than GDP. Analysis of the energy intensity change indicates that the effect of greater production in energy intensive sectors was outweighed by a decline in the household residual, a substitution of capital and labour for energy, and specific energy efficiency improvements. Declining residential energy use per capita was thought to be due to a combination of greater energy efficiency and conservation, and the northward population drift.

There is confusion in many public commentaries on energy matters between "energy efficiency" and "energy intensity". Energy efficiency is only one of the factors affecting energy intensity. Conversely, changes in energy intensity may not be indicative of shifts in energy efficiency. Analysis of energy intensity trends can provide an indication of changes in energy efficiency, but the present relatively high level of energy intensity in New Zealand does not mean that the country is markedly less efficient in its use of energy than many other countries.

Energy Efficiency Potential

Energy efficiency means using less energy to get the same result, or getting more results from a given amount of energy. This publication looks at energy efficiency measures that have potential to lower the economic, environmental and social costs of energy use per unit of output — manufactured products, transport services, home comfort, etc.

The question of the potential for energy efficiency in New Zealand can be addressed via an industry-by-industry approach that develops best-practice benchmarks. Alternatively, a sector and technology approach might be useful. Both of these techniques can be worked into computer modelling exercises.

Benchmarks are specific energy figures, such as the amount of consumer energy to produce a tonne of steel. Overseas experience can be used in benchmarking, but it is also important to take into account local conditions (energy prices and other resource realities) by examining the top performing plants in New Zealand. This publication, Volume 2 in particular, provides information on benchmarking methodologies.

With a sector- and technology-based approach, cost-effective technologies and management systems applicable to a sector are identified. The opportunities for implementing these technologies across the sector and the degree to which these have already been adopted are assessed. This approach provides an indication of the amount of energy efficiency improvements that remain under present economic conditions.

Efficiency gains might come about through better use of a single energy source, electricity say, or through fuel switching. Fuel switching can work two ways. Replacing electric resistance loads with natural gas use can improve efficiency. Replacing natural gas, coal and oil plant with electro-technologies (using mechanical vapour recompression to dry timber, for example) can also improve energy efficiency. As noted earlier, efficiency improvements can also be made on the supply side, such as through better conversion of primary energy . The following outlines recent estimates of the energy efficiency potential that is likely to be available in New Zealand.

In 1992, ECNZ released a report entitled "The Developing Market for Energy Efficiency in New Zealand". This paper developed and analysed a number of scenarios, each with different assumptions about the introduction of energy efficiency technologies between 1990 and 2005. This work provides an idea of the maximum energy efficiency potential and the implications of trying to achieve this.

The modelling exercise was used to examine two scenarios, the standard and efficiency scenarios. A bottom-up approach, tracing the changes likely in the development paths of 31 different sectors of the New Zealand economy, was used to examine likely outcomes. A mix of data from benchmarking and sector and technology methods underpinned the approach.

The standard scenario represents a business-as-usual approach to energy efficiency and energy use. Energy efficiency is taken as a low business priority. The scenario uses existing rates of turnover for equipment and building stock. Existing technology is assumed to be replaced in most sectors by the currently best available technology within 15 years. The currently best available technology means equipment and practices that are both commercially viable and considered the most efficient means of providing the energy service in question.

The efficiency scenario uses accelerated rates of equipment turnover and assumes that state-of-the-art technology would progressively replace existing technology in most sectors within 15 years. State-of-the-art technologies are the most efficient means of providing an energy service using current knowledge. Compared with the best available technology, they use less energy and provide lower operating costs, but are usually more expensive to install and have longer pay back periods. The key points of comparison between the two scenarios are presented in Table 2.

Technology improvements and increased use of cogeneration under the efficiency scenario help to break the GDP-energy use relationships experienced up to 1990. Consequently, there is a 47% increase in GDP with an 8% reduction in consumer energy. The standard scenario has a 45% growth in GDP, but a 13% rise in consumer energy.

The extra investment required for the efficiency scenario pays off well in the medium and long term. Using state-of-the-art technology does not hinder economic growth. Instead, it lowers energy costs and provides significant environmental returns. It would neutralise electricity load growth until at least 2005 (the end of the scenario analysis period) so that no new power stations would be needed in the interim. The resultant improvement in all forms of energy use translates into a 4% reduction in carbon dioxide emissions from 1990 levels by 2005.

Parameter 1990-2005	Standard	Efficiency
Primary Energy	plus 14%	fall 2%
Consumer Energy	plus 13%	fall 8%
GDP Growth	plus 45%	plus 47%
Additional Generation	plus 500 MW	Nil
Carbon Dioxide Emissions	plus 36%	fall 4%
Primary Conversion Eff.	down 1%	gain 3%
Consumer Conversion Eff.	gain 1%	gain 11%

Table 2: Energy efficiency scenarios — key results (ECNZ, 1992)

The efficiency scenario involved investments that some businesses may not be able or willing to make at present. The standard scenario involved many lost opportunities in that not all businesses were assumed to invest in energy efficiency even though this would be profitable. The true potential for cost-effective energy efficiency in New Zealand probably lies between the two scenarios.

A 1993 report to government officials provided a conservative estimate of actual energy efficiency potential (Harris, 1993). The report did not take a best case approach, that is, it did not assume that all cost-effective opportunities would be taken up. Instead, an attempt was made to identify realistic penetration rates for each technology given a concerted government funded programme. The programme proposed consisted of an expanded role for the Energy Efficiency and Conservation Authority (EECA), the adoption of minimum energy performance standards, the development of a market for energy service companies and the implementation of a comprehensive communication strategy to reduce domestic energy use.

Ministry of Commerce 1992 forecasts were used to produce a baseline energy use pattern for the year 2005 and energy efficiency opportunities were measured against this baseline. Energy use in the domestic sector had the potential to be 11% lower than the baseline in 2005. For this sector, energy use could in fact fall by almost 5% between 1990 and 2005. Energy use in other sectors would rise even with a concerted effort, but considerable savings were possible compared with the business-as-usual baseline case.

The commercial sector (retailing, services, institutions, etc.) had the potential for a 8.5% savings through energy efficiency, compared to the business-as-usual case, by 2005. It was assumed that energy efficiency investments in the major energy using industries — aluminium, iron, steel, forestry and petrochemicals — would take place without a special programme and would therefore form part of the baseline forecasts. A potential saving of 8% from investment in other industries was identified. The potential in the transport sector was thought to be 3%. The transport savings would largely occur as a result of commercial competition and through vehicle manufacturer initiatives.

A study undertaken for EECA in 1994 indicated that the sum of all cost-effective opportunities could be more than twice the estimates provided in the Ministry of Commerce Report (EECA, 1994b). The challenge is to find ways to motivate people to explore their energy efficient options and act on them. An important point is that once all the current cost-effective opportunities are taken up, that is not the end of the matter. Rising energy prices and/or innovation in efficiency technologies that lower costs or increase service open up a new range of opportunities.

Rationale for Energy Efficiency

Some of the advantages of energy efficiency have been alluded to above. This section provides examples of some of the commercial, national, environmental and private benefits.

Commercial Benefits

Initiatives to improve energy efficiency can provide excellent returns on investment. In some cases all that is required is management attention and changes to operations, such as better housekeeping. Where capital investment is required, most businesses will find they have some potential projects with payback periods of just two to three years. Attention to energy efficiency also pays off in terms of hedging against energy price rises, facilitating product quality, developing a dynamic corporate culture and providing a marketing edge.

Energy costs constitute a significant part of the overall cost of running some businesses. Nonetheless, in the past, management of most companies has often taken energy costs as given and focused attention on reducing or containing other costs such as raw materials, plant, accommodation and labour. Paying attention to energy costs will become increasingly important in the future.

Even where energy costs are a minor factor in the total cost of operating a business, it may still be worth considering energy efficiency as synergies are often found between energy efficiency and product quality, working conditions and occupational safety. These factors all help to maintain the product and cost advantage of a business in a competitive environment.

Placing an emphasis on energy efficiency can also be a good strategy for a business that works to establish a dynamic and innovative corporate culture. Allowing management and staff to participate in energy management is consistent with a corporate culture that devolves authority and responsibility.

In a world where consumers are being increasingly motivated by green issues, a business committed to energy efficiency can sell itself as a good corporate citizen. Product labelling schemes, such as “Environmental Choice New Zealand”, are being developed to assist consumers to bring environmental impacts into purchasing decisions. Energy inputs into manufacturing and product distribution are considerations for such labelling schemes.

National Benefits

For an efficient economy, energy services should be available at the lowest overall cost to society. In many instances, energy efficiency investment is a more economic strategy than further development of energy resources. Energy efficiency reduces the need for investment in transmission and distribution systems and energy losses in these systems.

New Zealand is currently experiencing strong economic growth but at a time when it has limited capacity to increase energy supply without new investment in this sector. It would be unfortunate if investment that could have been used to maintain business growth was unnecessarily diverted into new energy supply projects. Attention to energy efficiency in government policy and in business and private planning is a key step towards an economically optimal energy supply system.

Over 45% of New Zealand's total primary energy supply comes from natural gas and associated condensates. While new gas field discoveries are likely, the amount of natural gas that can be extracted at affordable prices will be limited. Energy efficiency in gas-fired power generation and in direct gas uses will help to extend the life of the country's reserves thus mitigating against fuel price rises and enabling the country to get the maximum environmental advantage out of using natural gas compared with other fossil fuels.

A sustainable energy future is one where the energy systems are reliable and efficient, and create no significant irreversible adverse environmental effects. Greater use of renewable energy resources and energy efficiency are needed to move towards this ideal state. Furthermore, New Zealand is a signatory to the Framework Convention on Climate Change, which deals with management of greenhouse gas emissions and sinks. New Zealand, along with other developed nations, is obliged to reduce its emissions of greenhouse gases and energy efficiency is a major means to this end. Knowledge about how the country is dealing with reducing greenhouse gas emissions, improving energy efficiency, etc. could enhance New Zealand's "clean green" image and benefit tourism and exports.

Environmental Benefits

Fossil fuel energy systems create emissions of the greenhouse gases carbon dioxide, methane and nitrous oxide. Improved efficiency in the use of energy reduces these emissions. Burning fossil fuels and renewable fuels such as wood can also cause local air pollution and carbon monoxide from car exhausts can present a health hazard in congested cities. Aside from emissions, energy resource developments can have adverse impacts on habitats and human communities. Even development of renewable energy resources can cause this problem. In New Zealand, there has been controversy over modifications to rivers and lakes from hydroelectric development. Recent proposals for wind farms have evoked landscape preservation issues. Sustainable methods of producing energy are necessary but are not, on their own, a substitute for energy efficiency.

Personal Benefits

Just as energy efficiency can be a good business investment, it can also payoff at the household level. There is a growing awareness that the majority of New Zealand homes are neither adequately heated and ventilated nor kept dry enough for health and comfort, especially of young children. An attempt could be made to rectify these problems by using more space heating, but only at great expense to the household. Alternatively, a combination of energy efficiency initiatives and better controlled heating and ventilation could achieve this goal more effectively. Such measures as installing house insulation and the use of fluorescent light fittings provide a good return on investment or save money for little effort. Even where investment has to be financed, the cost of capital can be covered by the lower energy bills, thereby releasing funds for other priorities.

The environmental maxim is to think globally and act locally. Home life is an important part of the learning experiences for the next generation and energy efficiency lessons learnt at a young age can carry over into adult life.

Delivering Energy Efficiency

The uptake of energy efficiency improvements in New Zealand has not been high, notwithstanding the incentives provided by the benefits outlined above. This suggests a degree of failure of government policy and market performance in the past. Energy markets in New Zealand have been reformed and a major issue is whether they will do a better job of promoting energy efficiency than the previous arrangements.

In the electricity sector, for example, power generation, distribution and energy supply have been unbundled and are now operated as distinct businesses. Power companies now operate a line business that takes care of the local supply network and an energy supply business that focuses on selling electricity. Power companies can send electricity to customers using another company's distribution network, thus creating competition. The old exclusive franchise areas no longer apply. Similar reforms are underway in the natural gas industry.

Cross-subsidies between classes of consumer (e.g. private or commercial) have been largely removed from both the line and energy sales sides of electricity supply. Taxpayer subsidies to power generation were removed with the establishment of ECNZ as a State Owned Enterprise (SOE) operating on commercial principles. Such subsidies carry a risk of distorting investment decisions. It can be argued that one of the reasons energy efficiency did not receive sufficient attention in the past was because consumers did not pay the true cost of electricity supply and, therefore, could not realise the true benefits of improving their energy use.

Several contentious issues remain, however. To facilitate competition in power generation, ECNZ has been split creating a second SOE known as Contact Energy. Competition is expected to result in energy pricing based on the true marginal cost of supply. The true cost, however, should also include social and environmental costs. This also applies to the cost of road transport, the activity that uses the most consumer energy. For example, environmental advocates have argued a case for a carbon tax to reflect the global warming effects of fossil fuel energy use. Without price adjustments to reflect such externalities, energy efficiency investments and new energy supply projects cannot be properly compared by the marketplace.

Another issue that needs to be resolved is the question of whether or not line or network charges need to be increased to recover the cost of electricity or natural gas distribution. Distribution companies are natural monopolies and there is concern, based on the wide variation in network charges, that some companies are either making extraordinary profits or are still cross-subsidising their energy sales business from network charges. Furthermore, high network charges recovered as fixed or largely fixed charges reduce the incentive to make energy efficiency investments.

Even where the pricing signals are adequate and there is fair and open competition amongst energy suppliers, a medium-term problem can exist if there are not enough players of sufficient quality in the energy services industry, such as energy efficiency advisors, equipment suppliers, etc.

It is clear that energy pricing, on its own, will not significantly increase the uptake of energy efficient technologies and that there needs to be an overall change in people's attitude towards energy efficiency. Incentives are necessary, even in a well functioning market, but equally important is a supply of good information. This publication is intended to provide such information and, hopefully, encourage people to act on it. At the present time, the country has some way to go before there is widespread awareness of energy efficiency and the presence of a dynamic energy services industry able to provide the technical and financial services required.

In the electricity sector, some power companies do play a major role in providing energy efficiency advice. These companies recognise that the provision of such advice can give a marketing edge by helping to retain customer loyalty and by creating brand or service differentiation, etc. In other cases, such as when the distribution network is near capacity, the line side of the business may see energy efficiency as beneficial because it reduces peak loads.

There is, nevertheless, a concern that many power companies do not have a strong enough incentive to promote energy efficiency to all their customers. Whether or not these companies will be able to remain competitive in the longer term and avoid takeovers or amalgamations is questionable. Even if they disappear, their successors may still experience the same lack of incentives.

There is clearly a role for public policy to facilitate energy efficiency in a market environment.

Other countries that have deregulated their energy markets have created national energy efficiency programmes funded by energy sales levies or required the line businesses to spend minimum amounts on energy efficiency initiatives. They have also tended to take a more measured approach to the rate of deregulation, in contrast to the rapid change that has occurred in New Zealand. Furthermore, some countries have retained a degree of regulatory oversight of the market. The effectiveness of these measures has been variable. In New Zealand, light-handed regulation amounting to little more than a loose information disclosure regime is in place.

The government has, however, recognised the importance of energy efficiency and has in place several programmes that will help with its delivery. Some of these programmes, such as voluntary agreements on CO_2 reductions, are linked to FCCC obligations as well as energy directly. The government has funded EECA, which in turn runs a variety of programmes to facilitate energy efficiency, such as the Energy-Wise Companies campaign and the Crown Loans schemes. The problems of promoting energy efficiency to households in a newly developing free market recently gained recognition with the establishment of the Energy Saver Fund. This fund will be disbursed on a competitive basis to projects that aim to overcome barriers to household energy efficiency and to develop an energy services industry for residential energy use.

It is important that these types of initiatives work well. Market failure should not be compounded by government failure. To avoid this situation, the performance of the new energy markets and the uptake of energy efficiency in New Zealand should be closely monitored. The current information disclosure regime may not be adequate in this regard. Notwithstanding initiatives such as the Energy Saver Fund, barriers in some parts of the market may not be surmountable. For example, there is a case for minimum performances for some appliances. The level of information required for proper decision making in some parts of the marketplace is inadequate and may need to be dealt with by way of mandatory provision. Fuel efficiency disclosure for new cars may be a case in point. This report contains a range of public policy suggestions aimed at improving the delivery of energy efficiency.

References

Collins, C (1995). Estimates provided to CAE from two sources: *Energy Data File*, published periodically by the Energy and Resources Division of the Ministry of Commerce, Wellington; and Commerce (1994) below).

Harris, G et. al. (1993). *Promoting the Market for Energy Efficiency*, report to the Officials Committee on Energy Policy, Wellington.

Commerce (1994). *Energy Demand and Supply Scenarios to 2020*, Ministry of Commerce, Wellington.

EECA (1993). *Updating New Zealand's Energy Intensity Trends — What has Happened since 1984 and why?*, report to EECA by Massey University, Palmerston North.

EECA (1994a). "Is wasteful use of energy the cause of New Zealand's relatively high energy intensity?", *Energy-Wise Energy Efficiency Trends*, Bulletin 1, published by EECA, Wellington.

EECA (1994b). *Supply Curves and the Economic Potential for Improving Energy Efficiency in New Zealand*, a preliminary study commissioned for discussion purposes by EECA, Wellington.

ECNZ (1992). *The Developing Market for Energy Efficiency in New Zealand*, discussion paper prepared by the Electricity Corporation of New Zealand Limited, Wellington.

Volume 1: Summary

Part 1: Domestic Buildings

The domestic sector currently consumes mainly electricity (71%) for its energy use, although wood (14%), coal (7%) and gas (7%) are also used. The main uses of this energy are for space heating and hot water heating, which together account for 75% of the total energy use in a house. Forecasts suggest that the electricity and gas shares of residential energy use will continue to rise, while coal's share will decrease.

There are three major factors that affect the energy efficiency of a house: the design, the appliances within the house and how the homeowner uses the house. For New Zealand homes to become more energy efficient, all three factors will have to be considered at a national level. However, little is known about how much a change in behavioural habits will decrease the amount of energy used in a household. Better access to information about energy efficiency for all New Zealanders is required before behavioural changes can be made as people are often unaware of what can be done in their home to save energy.

Solar House Design

New Zealand has three to four hours of bright sun per day on average in the north or sunnier regions (e.g. Blenheim) and two to three hours in the south. This amounts to about 3 kWh of energy per square metre per day. Nearly all homes receive some space heating from the sun — the problem is how to convert the sunlight into useful energy.

The key factors involved in solar space heating are house location and design, system configuration, collector types, window design and thermal mass. However, it is not practical to build a comfortable home only heated by the sun. Some form of backup heating will be necessary for rooms with inadequate sun access or to provide heat early in the morning or during prolonged cold periods. Consequently, solar house design should be seen in the context of overall energy efficient practice. It is not a substitute for a well-insulated home, draughtproof, yet properly ventilated.

Passive solar design does not require radical departure from conventional construction methods. Careful attention to detail is required, however, particularly relating to insulation and allowance for expansion (especially in walls used for thermal storage). The cost of building in certain types of solar heating features, such as an insulated concrete floor slab, may not add to the cost of a new home.

The benefits of good solar design in New Zealand will depend mainly on geographic location, the collector type used and the area and standard of glazing or window insulation. The savings in the use of heaters to achieve a suitable level of year round comfort can vary from around 20% in Auckland for the least effective collector system to around 80% with the best system. In Invercargill, the range is thought to be from 20% to around 50%.

Importance of Thermal Mass

Hour-by-hour variations in outdoor temperature and in the solar intensity incident upon a building mean that it will experience swings in its internal temperature. The addition of significant quantities of high density material (for example, concrete or water) within the building envelope will reduce the extent of such temperature swings by acting as an energy flywheel, absorbing excesses of energy when internal temperatures are high and releasing absorbed energy back into the internal space when the space temperature falls.

The effective implementation of "thermal mass", however, requires an awareness of the interdependency it has with solar gains (generally via glazing), the insulative performance of the building envelope and the nature of the climatic variations to which the building is exposed. Even modest attempts to properly incorporate appropriate thermal mass into a modern New Zealand home can produce significant energy benefits. A national study of 28 houses showed that, on average, "standard" houses with a concrete floor slab saved 40% of space heating energy compared with equivalent timber floor houses.

Thermal mass is in something of a "come-from-behind" position in terms of awareness and in becoming widely considered and adopted in New Zealand. Given an appropriately-raised profile (and possibly direct inclusion within the building code), there is no reason why it should not receive much greater consideration in new house design and construction, if for no other reason than because the cost increment of adding it is insignificant in many instances (on flat sites, a concrete slab-on-ground may be cheaper than a suspended timber floor). It is fortunate that those regions of the country where the relative mildness of the climate make thermal mass most effective (Auckland region, in particular) are those with the highest proportion of our housing stock (present and likely future).

Insulation of New and Existing Homes

Insulating the exterior surface of a house helps to make the building more energy efficient and healthy. The energy-saving objective of insulation is to reduce heat loss so that the thermal performance of the building can be better managed. The insulation level and degree of infiltration in a building, together with the occupier's choice and use of heaters, and the control exercised over ventilation all interact to create the indoor climate.

In an uninsulated home, it may be possible to keep rooms generally warm enough through reducing draughts, limiting ventilation and using heaters frequently. This will be expensive and the lack of ventilation is a health concern. This concern is compounded by the likelihood that in parts of the building the heat gradient across the walls will be so sharp that condensation occurs. This can damage paint and furnishings directly or through mildew and mould and make the home unhealthy. It is better to improve the building than add large amounts of heat and compromise ventilation.

An important first step with both new and, especially, older homes is weatherstripping to reduce unmanaged loss of warm air and infiltration of cold outside air into the home (while ensuring that the house is still adequately ventilated). Only about one-third of New Zealand homes have been built to satisfy current insulation standards. A fraction of the balance may have had a degree of insulation retrofitted. The priority in a relatively draughtproof home where ventilation can be managed is ceiling insulation, followed by walls, windows and then the floor.

Some of the heat loss from homes occurs through conduction-convection as well as radiation, so the siting of the house and the condition of its immediate environs can affect its thermal performance. Placing a home so that it is sheltered from prevailing winds could be a useful strategy. Making use of the shelter provided by trees and adjacent structures may also be practical. Common sense is needed to avoid siting problems such as excessive shading.

Insulation has to be seen in the light of the need to improve our housing stock and make it more suitable for habitation. We generally need warmer and drier homes, and draughtproofing, insulation, double glazing and passive solar design will allow this to be achieved with less use of energy resources.

Glass and Insulation

Windows form an important function in building design. They admit light and solar heat, provide a view of the environment and, in most cases, can be opened for ventilation. In energy efficiency terms, however, windows are becoming the weakest link in the thermal insulation of a modern building as developments lag behind those in other areas.

Some 24% of the heat loss of an uninsulated house is through the windows. However, this figure increases significantly once all or part of the roof, floors and walls are insulated, and it is not unusual for half of the conduction losses to be through single-glazed windows. This, in combination with the New Zealand trend to use large glass areas in housing design, makes glazing an important element in an energy efficient home.

Traditionally, glass in New Zealand houses has been thin sheet glass, and more recently high-quality thicker float glass. The glass thickness for houses is normally determined by windload and human impact requirements in relation to the sizes of windows and doors; hence, as glazing area in houses has increased, the thickness of the glass used has also increased. The problem with single monolithic glass is that the thickness makes no real difference to the thermal insulation of the building.

There are several ways to improve the insulation of windows, the most common being the use of blinds, drapes and curtains (although these are only effective when selected and used properly). Double glazing is a less common but more effective method. Recent estimates indicate that only 7% of domestic windows are double-glazed, but the use of this technology is increasing as awareness of its benefits grows. As well as providing energy efficiency, double glazing reduces noise problems, increases security and avoids condensation.

Ventilation

Homes need adequate ventilation. However, ventilation means heat loss from the house on cold days, which makes home energy efficiency measures such as solar heating and insulation doubly important. Proper, managed ventilation can, however, be a direct energy efficiency strategy. The alternative to ventilation for moisture control is either extra heating or the use of dehumidifiers. The most energy efficient strategy will be the right mix of ventilation, heat and direct moisture control.

Background air infiltration provides a useful level of ventilation in most existing houses, but the trend in new houses is towards more airtight construction. This has led to air infiltration alone not providing the necessary background ventilation that was present in older homes and has created a need for a way of adding ventilation that is consistent with home security, weather tightness and draught control. Traditionally, windows have been used to provide extra ventilation, but open windows are insecure and not easily adjusted to provide ideal background levels of ventilation.

A good level of ventilation is represented by 0.5 air changes per hour (ac/h), but in a well insulated house this can contribute to 20% of the total envelope heat losses. Higher ventilation rates or moves to higher levels of insulation would increase this proportion. In the most extreme climates in other countries, mechanical ventilation systems are used to supply fresh air on the basis of occupancy or demand. This approach can be energy efficient where there is recovery of heat from exhaust air, but it does require houses to be constructed to a high level of airtightness.

In less severe climates, passive ventilation strategies (some window joinery now has built in vents) are used to provide background levels of ventilation. These strategies will often be combined with mechanical ventilators in bathroom and rangehoods to effectively remove moisture at the source. With its temperate climate, New Zealand is likely to favour passive strategies, although there are some scenarios that could bring about wider use of mechanical systems. The most likely of these would stem from the need to provide tight control on indoor moisture levels so that dust mites and mildew are not supported, and/or to provide filtered air for allergy and asthma sufferers.

Space Heating

New Zealand homes are generally underheated. Increasing comfort levels will require action to efficiently raise heat input and reduce losses. Solar gain, insulation and careful management of ventilation are important. Careful heater selection, installation and the use of controls will help to minimise the heat input needed to gain a given level of comfort.

The choice of heater or heating system is quite complex, but a number of considerations have been identified. These can be reduced to a series of key questions: what type of heat best suits the service requirements (e.g. infrared or warm air?); is the right amount of heat getting to the right place at the right time (thermostats and timers?); once it is delivered, is the best use and reuse being made of it (recirculation fans?); and finally, are there any downstream effects (pollution, increased ventilation needs, etc.) that need to be considered?

The energy efficiency of different types of heaters in terms of converting primary energy into a health and comfort service varies. In addition, a basically efficient heater can be applied to a task or operated in a manner that makes it inefficient. The secret is to put together a set of equipment and controls that provides the right answers to the key questions posed above.

Electric Space Heating

There is much room for improving heating systems in New Zealand houses in terms of both delivered comfort and efficiency. New Zealander's have historically tended to favour using a number of small- to medium-sized heaters (some or all of them portable) over central heating systems. Even with built-in thermostats and timers, these appliances have shortcomings. They are not the most energy efficient approach to electric space heating and are not likely to provide a high standard of indoor temperature control.

Over the last few years, power companies have been actively promoting nightstore heaters, to shift heating loads off-peak. The drawbacks of these heaters for some consumers has not been well publicized. These appliances are best suited to homes occupied all day rather than those with irregular or only evening occupancy.

Two modern heating options are emerging — low-temperature radiant systems and heat pumps. These modern technologies are suitable for partial home heating (that is heating only selected zones) or house-wide central heating systems. These systems are not cheap, but the investment involved usually means that the relatively small additional expense of installing effective controls, which can save money and energy, is seriously considered.

Improved controls offer much better thermal comfort and health, as well as significantly reduced energy costs from electric heating systems. Whether dispersed heaters or central heating is used, correctly placed thermostats and smart control units that can learn about the thermal performance of the house should be fitted. Controlling a heat pump with only a thermostat, for example, is likely to lead to intermittent heating, often using the inefficient resistance element, and will not realise the full potential of the technology. However, using logic controls to optimise heater start time to achieve a warm house in the morning could provide the highest performance at the lowest cost.

In the future, New Zealand houses with electric space heating will probably use low-temperature radiant heating and centralised heat pumps with control of the heat delivery by amount, time by zone. These technologies are available overseas and will become more widely used in New Zealand.

Solid Fuel Heating

At present, solid fuels (coal and wood) provide 52.8% of the total energy used for space heating and approximately 5% of the total energy used for water heating. There are over 352,000 enclosed fires and 322,000 open fires installed in New Zealand's 1.1 million homes, which consume approximately 100,000 tonnes of coal (including lignite) and more than 300,000 tonnes of wood each year.

In the 1992/93 year, 30,000 solid fuel heaters were manufactured in New Zealand, the majority of which were exported. New Zealand manufacturers are leaders in the design of freestanding stoves and pioneered the double burn concept. In the first half of 1993, solid fuel heater sales reached a ten-year high, reflecting people's concerns about the electricity shortages of the previous year and the anticipated rise in prices for the domestic consumer due to restructuring in the electricity industry.

Open fires are not energy efficient. Only a fraction of the heat content of wood and coal gets into the room. Furthermore, when not used, chimney draughts can create a major heat loss. Open fireplaces can be replaced with built-in modern enclosed heaters that are about three times more efficient. Where open fireplaces are retained for occasional use, the chimney should be safely blocked when there is no fire.

Free standing stoves are a good alternative to an open fireplace. The older pot belly type stoves have efficiencies of around 30% to 50%, which compares well with electric resistance heating using electricity from thermal power stations. Some modern free standing "double burning" stoves have efficiencies around 70% and can perform well at both high and low burn rates. There is, however, considerable variation in the efficiency of modern stoves, especially at medium and low burn rates, and potential purchasers should ask for test results before making a choice.

While rare in New Zealand, large central heating furnaces are available that can use coal or wood chips, or pellets made from sawdust, etc. These units can supply warm air or, more commonly, hot water for use in room radiators. Some have automatic fuel supply and can be effectively controlled to match output with space heating demand. Others rely on a single short daily burn with the resultant heat stored as hot water for subsequent use.

Natural Gas Heating

Natural gas appliances can be portable or fixed, radiant or convective (air heaters), room based or part of a central heating unit. Since natural gas is clean burning, gas appliances can also be flued or unflued. Unflued heaters are very efficient in that all the heat of combustion is placed into the room. However, the flue gases add to indoor pollution and extra room ventilation is required. This extra ventilation means that unflued appliance efficiency is usually quoted as 90%.

Flued gas-fired appliances roughly split into three efficiency categories according to the amount of energy they lose in their flue gas emissions. The first category comprises all conventional appliances: their traditional construction results in a modest annual in-use efficiency of around 50%. The second category consists of so-called improved efficiency appliances: these recover just enough heat from the flue gases to avoid condensation of the water vapour produced during combustion. They are often called "nearly condensing appliances" for that reason. The annual in-use efficiency of these appliances is around 70%. The third category is the higher efficiency category of fully condensing appliances, which have annual in-use efficiencies of 85% or more.

On a total energy basis, direct use of natural gas is more energy efficient than conventional electric resistance heating. Electric heat pump heating can be very energy efficient providing it is well controlled. Fully condensing gas heaters are comparable with heat pumps in efficiency terms. Like electric heating, to get the best comfort and energy use from gas appliances requires good controls.

The level of controls on gas appliances is usually a function of heater size and cost. Small heaters usually only have several heat settings. The next step is thermostatic controls on the heater. The larger and more expensive appliances have timer controls. Few, if any, room-based gas heaters available in New Zealand have remote thermostats. Central heating systems usually have good temperature and time control.

In addition to the direct combustion space heating appliances, there are other kinds of high-efficiency gas equipment appliances, such as natural gas engine driven heat pumps, cogeneration (CHP) units or heat transformers scaled for domestic use. Although sufficiently mature and capable of high efficiency levels, these technologies have failed to find widespread application in the domestic sector so far.

Domestic Water Heating

There are around 1.5 million water heating systems in New Zealand of which about 1.2 million are in houses. The balance are residential-scale (less than 500 litres) water heating units in commercial and industrial installations. Approximately 14% of the country's total energy use and 35% of electricity use occurs in homes, with some 40% of this being used for water heating. Any strategy for improving the efficiency of water heating and storage has to take into account the normal lifetime and turnover of water heating appliances. The typical life expectancy for the main types of heating appliances varies from 10 years (electric mains pressure units) to 30 years (low pressure electric units).

Each year, old stock is replaced and the total number of units expands slightly due to new housing. The total annual market for water heaters is of the order of 70,000 units. A rough market breakdown is thought to be: low pressure electric storage units (62%), mains pressure electric storage units (27%), instantaneous electric heaters (1.4%), natural gas and LPG storage units (7%), instantaneous gas and LPG units (1.4%) and solid fuel wetback, solar and electric heat pumps (1.4%).

The efficiency gains to be made in consumption hot water systems can be easily identified, but it is more difficult to quantify them and it is impossible to state categorically that the improvement in efficiency will translate into reduced electricity demand in direct proportion. This is because a considerable number of systems currently installed (estimated as over 60%) are, at times, unable to deliver the customer's needs. Therefore, improvements in efficiency may also be taken out in improved service ("clawback") rather than energy savings.

Residential water heating systems in New Zealand are generally not energy efficient. The dominant form of water heating is conventional cylinder and electric resistance elements. Up to 30% of the energy input to cylinders escapes as standing losses. Only 5% of existing electric water storage heaters meet the WaterMark "A" grade insulation standard. Over 750,000 residential units do not even meet the "B" grade insulation standard, so there is clearly room for substantial improvement.

It has been estimated that doubling the number of "A" grade water cylinders to 10% of the total would reduce water heating energy demand by 300 GWh per year. Significant gains can also be made from using cylinder wraps on old units. A recent study estimated that improved water heating systems (cylinder insulation, wraps, tempering valves, pipe insulation, etc.) in around 90% of homes would result in energy savings of at least 600 GWh per year. There may be some savings clawback but, nonetheless, the potential for energy efficiency is considerable.

There are barriers to improving the efficiency of hot water cylinders. They have a long life and some inefficient cylinders are recycled from one installation to another. When a hot water cylinder does fail, consumers often leave decisions on replacement to plumbers who generally have a low level of interest in the efficiency of hot water systems. Home builders focus on reducing costs rather than lifecycle costs. Building code requirements ensure a minimum of building envelope insulation, but there is no statutory minimum energy performance standards (MEPS) for hot water systems; the New Zealand Standards for hot water cylinder thermal performance are not mandatory.

Energy efficiency in providing hot water services extends beyond the issue of just heating and storing water. It also depends on consumption levels and patterns and total system design. Some aspects of consumption such as cold water clothes washing and low-flow shower heads have received attention, but the importance of wider system design has tended to be overlooked. System efficiency can be improved by lagging hot water distribution pipes, using tempering valves, installing cold water expansion valves, lagging vent pipes and installing heat traps, and placing pressure and temperature relief valves close to the cylinder.

The Energy Efficiency and Conservation Authority (EECA) is developing a hot water programme for introduction in 1995/96, which will attempt to address the barriers to efficient cylinders and lack of knowledge on system improvements by bringing together manufacturers, the trades, consumers and power companies in a cooperative venture.

Solar Water Heating

The amount of sunshine falling on the roof of a typical New Zealand house in a year is almost 200,000 kWh, or about 20 times its total electricity usage. Providing it can be converted to a useful form, solar energy could meet all residential energy needs. The main challenge is how to collect the energy given that both the source and household energy uses are intermittent and follow different patterns.

The main methods of utilising solar energy are high temperature heat using sunlight-concentrating devices, photovoltaic conversion and passive solar space heating and water heating. Photovoltaic conversion provides the most flexible energy form, namely electricity, which can be used for heating, appliances, etc. The efficiency of energy conversion is presently fairly low (less than 20%), however, and photovoltaic equipment is relatively expensive.

Direct passive solar water heating is a technically simple process, but innovative designs have been developed to improve the conversion efficiency and/or to reduce costs. In all cases, relatively common materials are used. There is a trend towards integrating the solar collector into the house roof both for aesthetic reasons and, in some cases, so that it can serve a structural as well as water heating function.

Solar water heating is considered environmentally benign. Solar systems use a renewable energy source, thereby conserving fossil fuel energy resources and avoiding greenhouse gas emissions. For economic reasons, a domestic solar system is usually designed to supply 50% to 75% of the energy required by the hot water systems. The balance comes from a backup system, electric, natural gas or solid fuel wetback.

The main disadvantage of solar water heating is that, like many other demand-side management measures, it requires a significant capital outlay. This investment is recouped in the form of electricity or gas cost savings. Household consumers may be put off by the up-front costs and businesses may find the payback periods lengthy. Economic analysis shows, however, that solar water heating is often competitive with all gas or electric systems and that the payback periods correspond to attractive rates of return on investment.

Domestic Lighting

The incandescent gas-filled tungsten filament bulb is almost the universal light technology in New Zealand homes at present. The most promising technology for the improvement of domestic lighting efficiency is the replacement of the incandescent bulb with fluorescent light sources, which are about five times more efficient and can last up to eight times as long. There is a realistic potential saving of 60% by using fluorescent lights in the main living areas of New Zealand homes. This improvement cannot all be achieved by simply retrofitting compact fluorescent lamps (CFLs) as replacements for incandescent bulbs. In many cases, it will be necessary to install purpose-built fluorescent luminaires.

Paybacks of 2.5 to five years seem typical where retrofit lamps are feasible, but can be as low as 1.6 years when comparing the initial purchase of incandescent versus fluorescent lamps and luminaries, as would be the case in a new house or major renovation project.

In some cases, conversion to fluorescent lamps will provide amenity benefits as well as cost savings. The light levels in many New Zealand homes are inadequate for certain tasks, particularly in the kitchen. If householders installed fluorescent light sources in their kitchens, for example, then light levels could be increased to provide a safer, more comfortable working environment without increasing electricity demand. Modern triphosphor tubes provide good colour rendering, unlike the earlier fluorescent tubes.

Tungsten halogen or quartz halogen light sources provide a bright, concentrated light source. They can be more energy efficient than conventional tungsten bulbs, but are not usually cost effective on the basis of their energy savings. They are usually installed for the amenity value they provide, especially as spot lights.

The greatest barrier to the uptake of more efficient fluorescent lighting technology is the lack of householder knowledge on the potential savings and the circumstances where these can be achieved. Were this problem solved, the next obstacle is that lighting retailers do not stock a wide selection of the retrofit CFLs or purpose-built fluorescent luminaires, and their staff often have little knowledge of fluorescent technology. To overcome these barriers and accelerate the uptake of fluorescent technology, an integrated approach is required. The first step in such an approach is provision of information and advice. Householders need to be better informed about lighting options and the same can be said of architects, builders, electricians and lighting salespersons. A change in public attitude would also be encouraged by general publicity on the desirability of energy efficiency.

Household Appliances

Space and water heating appliances have been covered above. Of all the other household appliances, the most important in energy terms are refrigerators and freezers, washing machines, dryers and stoves. Other appliances with the potential to materially impact on energy use, such as dehumidifiers and airconditioners, are now becoming more widely used in New Zealand homes. The energy consumption of appliances in the home is not well known; however, refrigeration is thought to account for 6% to 10% of total home demand, with cooking accounting for a further 6% to 8% and other uses 7% to 11%.

The increase in domestic (electric) appliances has, in most cases, been a phenomenon of the last few decades. Today the market is more or less saturated by ranges, microwaves, washing machines, refrigerators and radio and TV sets. The penetration is high for freezers, clothes dryers, dishwashers and video recorders. Other appliances such as garbage compactors, dehumidifiers, heat pumps and air conditioners are yet to make any significant impact in New Zealand. What happens to the national appliance energy consumption by the end of the century is a function of market penetration of appliances, their in-built efficiencies, their size and level of features and, from the point of view of the consumer, their patterns of use and replacement.

In New Zealand, there is quite reasonable data on new appliance energy consumption when measured against standardised tests. Other information on the number of new versus old appliances, the way appliances are used in the home, the amount of household energy they consume, etc., is poor to non-existent. This lack of information is a serious limitation when designing measures to promote energy efficiency and monitoring the results. Household surveys to obtain a cross-section of existing appliances and a manufacturer/retailer disclosure regime for major appliances (e.g. refrigerators) to track changes in the appliance population may be needed.

There is a case for minimum energy performance (MEPS) standards for the main appliances. These standards can be set on the basis of technical-economic criteria aimed at minimising lifecycle costs. MEPS can be gradually phased in with standards becoming progressively higher. Such standards are in use or are being developed in other countries. The need for harmonisation of trans-Tasman regulations under CER is also an issue to be considered.

Household Energy — Economics

Conventional wisdom has it that energy efficiency in the home is not very economical in New Zealand because energy prices are low, energy efficiency costs are high and the climate is so mild that energy saving measures are not really justified. All these assumptions are questionable. Many people do not appear to know how to apply economics to household energy efficiency decisions and are misled by economic terms such as the payback period. Most people are not able to compare this performance indicator with normal investment criteria such as bank interest rates. The problem is compounded by the assumption or advice put about that householders are, or should be, looking for short payback periods, possibly as low as two years.

Energy efficiency investments are not usually considered in the same rational light as other economic investments. An obsession with payback periods of less than two years indicates a perception of high risk or confusion about the value of energy savings when compared to other investments. Two-year payback investments correspond to return rates of over 50% per year, which are considered ridiculously favourable for other investments.

The use of the internal rate of return (IRR) to calculate the actual value of energy saving investments is recommended. A range of case studies illustrates the point that investments that may seem unattractive on the basis of their payback period can, in fact, represent excellent value for money. It is also noteworthy that household energy efficiency investments such as insulation, double glazing and lighting provide increased health, comfort and safety, as well as energy savings.

Lifecycle analysis that yields comparable annual costs and benefits for different levels of energy efficiency investment is also helpful. This technique can be used to find the optimal level of efficiency investment. While this type of analysis might be beyond most householders, it is a valuable tool for architects and engineers involved in such tasks as advising on building code standards, MEPS, etc.

Overcoming the Barriers

New Zealanders could improve the energy efficiency of their homes in ways that are not only economic but would also improve their quality of life. The opportunities available are not being fully exploited. It is difficult to list a clear-cut set of barriers to greater energy efficiency in homes. A factor that might be a barrier for one person or in one circumstance could provide a positive incentive for efficiency in another.

Our collective attitudes to household energy efficiency contain a mix of strengths and weaknesses. The design of steps to increase the uptake of energy efficiency will need to bear in mind the complex interplay of forces that shape behaviour. The final chapter in the Domestic Buildings part of Volume 1 provides some insights into designing these steps by examining a wide range of issues.

Householders are focused on the services energy provides, rather than on energy efficiency itself. This focus need not be a problem, however, if a strong connection is made between priorities for the home features and functions and energy efficiency. More information is needed linking factors such as comfort, health and safety with energy efficiency. It must be acknowledged that one of the barriers to the promotion of energy efficiency is the cost of electricity. New Zealand has the lowest residential electricity price of 21 modern countries recently surveyed. Nonetheless, within this economic restraint, there are still many cost effective opportunities being overlooked. Creative initiatives can put the focus on energy efficiency. The chapter on the economics of domestic energy efficiency concluded with two positive suggestions.

A good case can be made for extending the "qualifying ratio" used by lenders to decide whether potential borrowers can afford to service mortgage debts when the proposed purchase is an energy efficient home. Energy efficient houses provide their potential owners with the opportunity to reduce household expenses. In such cases, borrowers have greater budgetary flexibility and therefore are more financially secure and present lower risks. Another means to facilitate cost-effective energy efficiency is via power companies and other third party investors developing mechanisms to share the value of energy savings with their customers. Initiatives in the banking industry and energy services field will help the full value of potentially cost-effective energy savings available in New Zealand (in the order of $1 billion per year in 1994) to be realised.

Part 2: Commercial and Institutional Buildings

Institutional buildings range from multi-storey university and hospital buildings to residential-scale schools and community centres. Commercial buildings similarly range from large office blocks, retail complexes and hotel accommodation to small shops and workshops.

Commercial Sector Energy Use

The operation of commercial and institutional buildings accounts for the direct use of about 18.4% of New Zealand's electricity and 5.3% of its fossil fuels. Energy is also required to manufacture and transport construction materials as well as to erect the building. This embodied energy is significant and reducible, but the focus here is only on opportunities to reduce the energy used in the day-to-day operation of buildings.

In 1990, the sector contained over 42,000 buildings totalling some 40 million square metres of floor space. However, the commercial sector's floor area and energy use is concentrated in the larger buildings; just 345 buildings over 10,000 m^2 in the health, education and office subsectors account for 24% of the sector floor area and probably about 30% of electricity use.

Lighting and airconditioning (including heating, cooling and distribution equipment) are the major end uses in offices. Heating water, a major energy use in homes, is only a significant factor in hospitals and residential institutions, and even in these buildings it is well behind heating as an energy load.

Energy efficiency in buildings can be increased by attention to building design (including construction and commissioning), use of new technologies and the practice of sound management techniques. Sound management alone can reduce energy demand by up to 20% in some cases.

In the short term, refurbishments, retrofits and improved management of existing buildings will offer the greatest opportunity for increasing energy efficiency in the sector. In the longer term, energy efficient design will become increasingly important. The use of energy efficiency design assistance prior to construction can yield savings of up to 75%.

Where retrofits are primarily driven by the desire to improve energy efficiency and reduce costs, energy savings by end use of 15% to 25% for heating and 25% to 40% for lighting are possible for existing buildings. Where energy efficiency measures are incorporated into a major retrofit or a refurbishment that is being carried out for other reasons, the potential for cost-effective energy savings can approach that for new buildings.

Building Design

There has been a worldwide trend in recent decades for commercial buildings to be dependent on mechanical systems to produce acceptable internal comfort conditions. The resulting buildings, while producing uniform internal environments, are heavily reliant on fossil fuels and other nonrenewable resources. In addition, toxic emissions from building materials often lead to indoor air quality health issues. While the use of efficient plant has mitigated energy demands, the basic form of many modern buildings is not conducive to energy efficiency and a pleasant working environment.

With careful design, it is possible to provide buildings that are pleasant to work in, energy efficient, and sustainable in a broad sense. The building form that helps to achieve this result can be described as climate adapting, as opposed to the climate rejecting design of most modern buildings. Climate adapting buildings tend to have an increased surface area with atria or lightwells, use thermal mass to stabilise temperatures or create passive ventilation, and provide as much individual control for occupants as possible. Such a work-with-nature approach, rather than complete reliance on superimposed HVAC systems, could save substantial amounts of energy.

Any move to a sustainable built environment will, however, demand more than just "energy efficient" buildings. City infrastructure also warrants consideration. Close proximity of place of residence and place of work will be essential. As well as reducing transport energy use, this proximity will lead to a change in the basic one-use or single purpose characteristic of the "commercial building". Buildings will serve several uses, either during their life or at any one time.

One of the problems with current building design practice, and arguably a barrier to sustainable architecture, is that the building envelope and form, and the lighting and HVAC systems are the domain of different professional groups. Computer simulation tools are being developed that enable the integrated design of buildings. These tools can facilitate greater professional interaction and the optimisation of such matters as building thermal mass, glazing and HVAC performance.

Modern design tools can be used to assess the energy demands, lighting performance, aesthetics and other characteristics of a building as work progresses from pre-design planning through to final plans and specification. The key feature of these design tools is their ability to handle large amounts of data and to integrate a wide range of building performance criteria. Consequently, they can play an important role in providing more energy efficient building designs. The need to increase the use and effectiveness of these tools and ways to improve the tools currently available are discussed in the report.

New Technologies — Lighting

Lighting is arguably one of the most important energy aspects of modern buildings. Artificial lighting invariably uses electricity, an expensive form of energy, and the heat from inefficient lighting adds considerably to HVAC loads. A range of energy efficient technologies are available that combine efficient fluorescent tubes and reflectors with electronic ballasts and controls. A modern, energy efficient lighting retrofit can perform so well that in many cases it is commercially viable to scrap existing lighting systems, even if they still have some useful life remaining.

A key point in the discussion of lighting options is that the techniques for saving energy through lighting changes are relatively simple, well-proven, beneficial and save money. Savings can, on the whole, be accurately calculated in advance and require neither "guestimates" nor expensive and time-consuming computer modelling and monitoring. Such techniques for reducing lighting energy consumption are:

- effective — simple payback periods of less than three years are commonplace, but measures that have payback periods of up to five years or even more should be acceptable, especially where lifecycle costing of building projects is under consideration; and
- user-friendly — in other words, do not entail a worsening of the existing or planned working environment. In fact, there may well be positive side-effects in the form of better light quality, reduced maintenance costs, improved staff comfort and health, and even higher lighting levels.

Even improvements to recently completed buildings are possible because of developments in energy efficiency technologies since the building was designed.

Commercial HVAC

In considering HVAC systems, the emphasis is on the reduction of heat gain, the use of cool outside air when possible, the installation of efficient plant and maximising opportunities for passive cooling and ventilation.

Gain avoidance techniques include good selection of building orientation and shape at the design stage, the use of roof wetting, installation of advanced glazings, efficient lighting and office equipment. Passive cooling and ventilation techniques include earth berming, the use of shading and thermal mass. Often the outside air temperature is low enough to provide useful cooling. For example, an air-side economiser to use outside air can provide up to 77% of the total cooling energy in Wellington.

On the question of plant selection, no single technology stands out in the HVAC area. Substantial gains can be made by a combination of equipment and practices such as increasing the size of heat exchangers, lowering condenser head pressures, correct maintenance, good choice of motors and fans, effective duct sealing, use of computer controls, etc.

Using a combination of gain avoidance (both internal and external), more efficient mechanical cooling (with parasitic power reduction), appropriate supplemental alternative cooling and improved controls, energy savings of up to 50% to 90% can be made. Such savings can be made utilising off-the-shelf components and proven technologies applicable to both retrofit situations and new buildings. Furthermore, during new construction or major renovations, HVAC downsizing (due to reduced loads) can save significant amounts of capital. Taken with the increased rentable space (from smaller and quieter equipment), the cost-effectiveness of these measures becomes very attractive.

Office Equipment

The use of office equipment is becoming a major energy efficiency issue because as well as consuming electricity, office equipment — like lighting — also contributes to the heat load.

There has been a dramatic change occurring in the way information is processed in buildings over the last 15 years. While there has been rapid growth in paper-based technologies (printers, copiers and fax machines), there has also been a partial transition from paper tasks to screen-based tasks. In many businesses, office automation has been decentralised, and personal computers, local printers and copiers have displaced mainframe computers and centralised printing and copying. This revolution has been one of the more significant factors affecting changes in energy intensity in the commercial and institutional sector and poses a number of challenges for building professionals.

The electrical engineer has to provide for growing power demands (the increased wiring adds to capital costs). The lighting designer has to rethink strategies to control glare from artificial lighting on vertical screens while still providing adequate illumination for paper tasks. The architect needs to prevent windows from becoming sources of both glare on screens and unwanted solar gain to compound the internal heat gain from equipment. The airconditioning designer has to contend with increased heat gain from office automation equipment, which must be handled by the general airconditioning system rather than by the dedicated plant that served the centralised mainframe computers of the past.

A wide range of energy efficient office equipment technologies are available or under development. Proven technologies include inkjet printing and "Energy Star" computer features that automatically put the equipment into a low power state when unattended. If such features are not present or activated, office workers can play a useful role by simply turning off their PCs when they leave their workstations. Laptop computers, often present on office desks, are usually more efficient than PCs. Technologies under development include cold fusing printing.

Management Techniques

The operation of a building can impact on energy use considerably, with well-operated buildings using significantly less energy than those that are poorly operated. Some of the technologies and techniques available to help building owners and managers improve the operation of buildings from an energy perspective are preventive maintenance, energy management programmes, monitoring and targeting and building energy management systems. All of these require a degree of cooperation from building occupants.

The response of people to their environments is an important consideration as "hardware" approaches to energy management problems are often defeated by building occupants. Tight seals around doors and windows are useless if doors and windows are kept open. Building occupants have no choice but to turn all of the lights on or all of them off if there is only one lighting zone and no individual controls.

Even without bringing in major new equipment or sophisticated computer controls, simple technology and management changes can improve energy use (for example, making schedules for turning off lights, using automatic timing controls for heating and lighting, regular equipment maintenance and the scheduling of building usage to concentrate activities).

A key step in implementing energy efficiency measures in commercial buildings is to develop an energy management programme. Such a programme should develop commitment to making improvements, assign responsibilities and identify energy use targets against which actual progress should be measured. Elements of the programme can be supported by computerised monitoring and targeting (M&T) systems, which can help to realise 5% to 20% energy savings for negligible investment. Building operation can be further enhanced by using building energy management systems that optimally control energy services and interface with M&T systems.

Public Policy

The marketplace, subject as it is to such information as price signals, incentives and so on, does not effectively deliver energy efficient buildings. There are barriers at various points in the design and operation of commercial buildings that need to be addressed. Some of these barriers are similar to those present in the domestic building sector and one of the remedies in that sector, the use of building codes, is likely to be applicable to commercial buildings as well.

Part 3: Transport

Internal transport consumes about 40% of consumer energy in New Zealand (around 140 PJ in 1993), a proportion higher than in most European countries and on a par with Australia and the USA. If international transport that is refuelled in New Zealand is also included (an additional 32 PJ in 1993), then transport in total makes up over 43% of the consumer energy demand in New Zealand.

On a per capita basis, New Zealanders use about 14 GJ/head/year to provide heating, lighting, etc. for their homes. The equivalent figure for passenger and freight transport (an estimated 42 GJ/head/year) is approximately three times the household energy demand. On average, each New Zealander uses just over half this total, perhaps 25 GJ for personal mobility — travelling to work, flying between cities, etc. Personal travel in New Zealand is estimated to be around 11,000 km per person per year. With the exception of the US where the total travel per capita is about 22,000 km, most developed countries have similar levels to New Zealand. Car travel accounts for 80% to 85% of passenger-km in most developed countries, including New Zealand.

Car ownership in New Zealand is one of the highest in the world and is still growing. Among the OECD nations, New Zealand car ownership, at just over 500 cars per 1000 people, is second only to the United States (just over 570 cars per 1000 people). The specific energy intensity of car travel in New Zealand is thought to be just over 2 MJ per passenger-km, which is higher than for most European countries (except West Germany), but lower than for the USA (2.7 MJ/p-km).

Road transport is the predominant user of energy within New Zealand, accounting for 90% of total transport energy demand. Just over half this demand is created by motor cars. The next largest user is domestic air transport (7%), with rail and coastal shipping accounting for the remaining 3% of use. Around half the transport energy used is in motor cars. A small amount is used for buses and taxis and the balance for goods transport.

Currently, on a per capita basis, transport energy demand is growing at 2.5% per annum, which, coupled with population growth, gives a total increase of over 3%. In the future, the rate of growth is expected to ease but will still be significant. The average rate of growth in the transport sector over the 30 years from 1990 to 2020 is expected to be around 1.8% each year and its share of total consumer energy could increase from 43% to nearly 50% over this time period.

New Zealand Circumstances

New Zealand's geography and history has shaped the development of its settlements and transportation systems and this, in turn, has contributed towards the pattern of energy use. As an island nation, New Zealand has no external land borders and all overseas transport is dependent on sea and air. Relatively long international journeys are necessary when compared to most other countries, but, at the same time, New Zealand is highly dependent upon its external trade. Internally, the two main islands dictate the need for inter-island transport by air or sea, and the elongated shape of the country makes for relatively long inter-urban routes in relation to the country's population density. The low urban density and dispersed settlement pattern is the rule in all but a few instances.

Car ownership grew rapidly after World War II, despite import controls that remained until the 1970s, and there is no sign that the demand is becoming saturated. This growth has weakened the position of public transport, which has seen a gradual but continuous erosion of its market over time. It does not appear to be economic to reverse this trend, except in a few main centres . It may be that the externalities of car transport (e.g. pollution) are under priced. If so, correcting this problem would expand the opportunities for cost-effective public transport. Nonetheless, for the foreseeable future the dominant mode for personal mobility in New Zealand is likely to remain the motor car.

Cars and Motorcycles

The New Zealand vehicle fleet is old in comparison with other western industrialised nations. For example, the average age of private cars is 10.6 years. The average age of cars is increasing, notwithstanding the influx of used Japanese vehicles, which now account for about 16% of cars on the road. These imports have displaced some older vehicles but have also cut into new car sales.

The average engine capacity of cars in use is currently just below 1.9 litres. It appears to be rising due to a drop in market share for small cars (under 1.35 litres) and increase in market share for cars over 2.0 litres. Company cars are thought to have larger engines on average than household cars and have higher annual utilisation, at 20,000 km/year compared with 13,300 km/yr for the car fleet as a whole. Motorcycles form only 8.4% of all vehicles and the total number is in sharp decline, falling from around 150,000 a decade ago, to only about 74,000 now.

The proportion of the car fleet that uses fuels other than petrol are 1.3% diesel, 1.7% CNG and 0.9% LPG. Diesel-powered cars formed a very small part of the fleet until the large increase in used car imports, which account for 80% of the diesel cars now in use.

Limited data makes it very difficult to estimate trends in transport energy efficiency. If current estimates are correct, then the intensity of private cars improved (that is fell) by 13% from 1975 to 1986 and by a further 8% from 1986 to 1992 to around 2 MJ/p-km. These gains have been due to improved vehicle technologies, which have been sufficient to counter the increased use of energy-consuming accessories and a declining occupancy rate; the average occupancy of cars is thought to be 1.12 persons.

Buses and Heavy Vehicles

The average age of heavy diesel goods vehicles is 9.9 years and diesel buses, 12.6 years. There are some 6000 large buses in use, of which two-thirds are diesel-powered, about 2% CNG powered and about 2% LPG powered. The balance are petrol-fuelled, with the exception of Wellington’s 70 trolleybuses. Heavy freight vehicles are almost entirely powered by diesel engines, whereas light goods vehicles, such as courier vans, appear to have a mix of petrol, diesel, CNG and LPG-powered engines.

The average annual kilometres travelled for light goods vehicles with diesel engines is around 17,000 km/yr (from Road User Charges data). The average utilisation for heavy vehicles has risen by around 40% since transport deregulation in 1986/87 to over 50,000 km/yr. A small percentage of heavy vehicles is likely to be clocking up high mileages and these long-haul truck units should be the main focus of energy efficiency initiatives for road freight.

The patronage of urban transport services is slowly declining, with a few exceptions. This trend, together with other factors such as increased urban congestion, has outweighed technology advances so that the energy intensity of bus transport has risen 10% from 1985 to 1992 to a level of around 0.8 MJ/p-km. Increases in load factor, especially for heavy vehicles, conversion to diesel and other technological advances, such as light weight bodies, have combined to improve the average energy efficiency of road freight by 7% from 1985 to 1992. Long distance line haul, the most efficient form of road freight, is now considered to be on a par with rail and coastal shipping, with an energy intensity of 0.75 MJ/tonne-km.

Rail, Sea and Air Transport

Historically, the railways system was operated as a government department and protected against competition from road freight transport. During the 1980s, this protection was gradually removed, creating competition between road and rail freight. This was followed by a programme leading to privatisation of New Zealand Rail, drastically reducing the staff numbers and causing the shedding of some of the less profitable business, particularly inter-urban passenger services. However, the reduction in freight tonnage was relatively minor and the company is now trading profitably, a considerable achievement over its days as a heavily state-subsidised government department.

Passenger rail intensity has changed little over the decade 1985-1995, possibly due to declining patronage countering technical improvements. There have been gradual improvements in the energy efficiency of rail freight transport over the years, from 1.00 MJ/tonne-km in 1970 to 0.77 MJ/tonne-km in 1992 (i.e. a little over 1% per annum). These gains are attributable to a variety of technical and organisational improvements.

Milestones for rail have included the replacement of the Wellington suburban railcars in the early 1980s, the electrification of part of the Main Trunk Line and the introduction of diesel-electric multiple units to the Auckland suburban service.

Coastal shipping services are provided by a relatively small number of vessels, carrying mostly liquid and dry bulk cargos. Coastal cargo services suffered a decline in the 1970s and through the first half of the 1980s. This was brought about by competition from other modes of transport and through outdated industrial practices in the ports and shipping industry. The second half of the 1980s and the early 1990s have seen many of these constraints dismantled and coastal shipping, which appeared to be on the brink of collapse, has made a recovery to its former levels of the early 1970s. However, there appears to have been little change in the energy efficiency of coastal shipping, despite a gradual increase in vessel size.

Domestic air transport is dominated by two main carriers, Air New Zealand and Ansett New Zealand. Air freight is very energy intensive. It is hard to separate from passenger transport, but is thought to require around 15 GJ/tonne-km. In 1990, domestic passenger air transport had an average energy intensity of 4.3 MJ/p-km, a significant 30% increase over 1987 levels, the year Ansett was allowed to compete against the national carrier. This change saw a considerable improvement in customer services but was accompanied by a reduction in overall load factors, which was sufficient to more than counteract energy efficiency improvements from the introduction of new aircraft. Air transport provides an example of where government's wider economic policy objectives can run counter to improving energy efficiency.

Energy Efficiency in Transport

Sources of improved energy efficiency or ways in which energy efficiency in the transport system can be improved include:

- vehicle technology advances (driven by competition within the industry, by consumer demands and perceptions and, in some cases, by government regulation);
- improved load factors (in general, the higher the load factor the better the energy efficiency);
- substitution of one vehicle type with another (for example, alternative fuel/propulsion systems and substitutions of transport mode);
- modification of the demand for transport (demand can be generated or suppressed by changes in the cost of travel, where "cost" is interpreted in a general sense as meaning length of time, financial cost, comfort and convenience); and
- driver education.

The above fuel efficiency measures are generally listed in order of increasing impact or degree of change from the present socioeconomic and values status quo. The greater the change required, whether in technology, the built environment or in human behaviour patterns, the harder this is to achieve and the longer it takes. It is generally recognised that achieving more energy efficient transport, especially for personal mobility, will be difficult given the reliance on and attachment to car use in New Zealand.

The relatively low price of transport fuels in New Zealand (the petrol price is fifth lowest amongst 23 OECD nations) and the small role fuel purchases play in the total cost of car ownership (they only make up 10% of the total cost) suggest that the marketplace will not deliver energy efficiency to at least 50% of road transport energy consumers, i.e. car users. Public policy can change the behaviour of the market so that changes occur more rapidly than they would otherwise and obstacles to the uptake of energy efficiency technologies are overcome. The main stakeholders in the transport sector should be noted and their motivations and circumstances understood when developing policy.

The main policy focus should be on encouraging people to operate vehicles more efficiently, i.e. to drive them economically, consider whether they can be better shared (the average occupancy is only 1.1 persons) and to question the need for some trips at all. Initiatives that would help in this regard include provision of information on vehicle fuel efficiency, encouragement for the use of alternative fuels such as CNG, more widespread driving skills education and incorporation of externality costs (for example, environmental impacts) into fuel prices. In some urban areas, a variety of measures to discourage car use, such as parking restrictions, and to improve the quality and frequency of public transport may be appropriate. The use of light rail, in particular, warrants careful consideration in several urban areas. Opportunities to reduce the need to travel via careful land and transport planning can arise during expansion, refinement and renewal of urban areas, and these should be taken up.

Motor Vehicles and Fuels

There are a variety of emerging technologies that will make motor cars inherently more efficient in the future. These include improvements to engine and transmission systems, the use of lightweight materials, better aerodynamics, development of low loss tyres, reductions in accessory loads and the use of energy "recycling" techniques. Many of these basic principles and technologies are also relevant to other motor vehicles, such as light vans, buses and trucks.

Ultimately, the net effect of applying a range of new technologies to cars and light vans could be a 50% to 75% reduction in fuel consumption. However, an improvement of this magnitude could be more than a decade away. The relatively affordable price of petrol and diesel and the commitment of manufacturers to incremental development of current technologies and production methods may slow progress. Nonetheless, there are many economically attractive opportunities for research and development, the results of which could push along the demand for very efficient vehicles.

In the area of alternative fuels and engine systems, the most likely development over the next ten years is the use of optimised four-stroke CNG and LPG engines. Unfortunately, as other parts of the world take a greater interest in CNG and LPG, New Zealand is in danger of losing its CNG infrastructure. Electric vehicles using mains-charged batteries are likely to only play a minor and transitional role to lighter and more flexible electric-hybrid systems.

Surprisingly little of the energy in fuel, typically less than 20%, is converted into power at the wheels. Better valve controls, fuel supply and combustion conditions, including lean burn, and automatic engine switch-off when parked in traffic can raise the low-load performance of the conventional petrol or diesel engine to around 25%. This is still well short of its full load potential of around 33%. Other technologies, such as constantly variable transmission systems, allow a car engine to operate more efficiently across a range of vehicle speeds.

Another approach is to use a small engine operating at high load, either to drive the vehicle directly, or to charge batteries for an electric engine. In the former case, the engine may be inadequate for peak acceleration and top speed requirements. This problem can be dealt with by having a second engine, which could be electric, for these situations. This line of thinking has lead to various efficient engine-electric motor hybrid configurations.

The motor car is likely to become much lighter and more streamlined in future. As a result, it could be readily driven by an electric-hybrid engine. Efficient two-stroke petrol or lightweight diesel engines will be suitable as the source of on-board power. Later, Stirling engines and ultimately fuel cells could be used to provide electrical energy. Regenerative braking will be a standard feature. These cars are also likely to use solar panels to run accessories such as interior cooling fans when parked in the sun.

Within ten years, it is conceivable that fuel cells, possibly combined with gas turbines, will come into use on heavy vehicles. The final drive for these vehicles is likely to be electric, which can provide very good torque characteristics and regenerative braking. This innovation will be aided by development of rapid discharge battery or other high density, easily-tapped energy storage systems, such as flywheels or ultra capacitors.

The development of alcohol fuels from biomass presents a great opportunity for New Zealand with its significant forest resource and potential to grow energy crops. Alcohols can be used in a wide range of engines, from internal combustion through to fuel cells. They are also easily stored and have a reasonably high energy density (similar to LPG). While hydrogen has many environmental advantages and can be manufactured from renewably sourced electric energy such as windpower or renewable biomass, its low energy density will probably limit its use in transport for some time to come. Its first commercial applications will probably be in heavy road transport, rail and shipping.

Infrastructure and Driver Performance

Both the road system and driver performance can also have an impact on energy efficiency. There is often potential for improving the road network to increase energy efficiency with new motorways, bypass roads, perimeter roads, etc., but this could be counterproductive in some cases. In the absence of travel consumption dampening measures such as road pricing or parking restrictions, major network improvements could facilitate even greater road use.

Relatively localised network improvements, such as the creation of one-way streets, tends to improve traffic flows. This could lead to improved energy efficiency, but possibly at the expense of other modes such as walking and cycling. It is important that road planners recognise the interdependence of the various transport modes and the possibility that improvements in one area can mean problems elsewhere.

Information and communication technologies can improve the way the road network is used and managed by traffic controllers, motorists, public transport operators and their passengers. Examples include traffic and control monitoring to reduce stop-start driving; provision of information to drivers to enable them to make sound route and speed choices (e.g. to avoid congestion); monitoring of individual vehicles to restrict access to certain areas, to levy tolls or congestion charges, or to provide information to facilitate public transport.

Generally, with careful planning, information technologies can be used to increase energy efficiency for road users without detriment to other modes. Estimates of the efficiency savings for car drivers from better traffic control and routing advice, for example, generally fall in the range of 5% to 10%.

Driver education and training has the potential for quick and significant energy efficiency gains together with other benefits, such as improved road safety. Experience indicates that a sustained programme is needed, however, to ensure the changes in behaviour eventually become permanent. Most drivers can improve their fuel economy by 10%. The fuel economy difference between aggressive and fuel efficient driving can be 20% or more. Training programmes for fleet drivers can be reinforced with on-going fuel consumption monitoring systems. Practical experience with fleet-based systems indicate that savings in the order of 5% are possible through changing driving styles and improved vehicle maintenance. While this saving is small, it often requires little expenditure.

To varying degrees, drivers are also responsible for the maintenance and setup of their vehicles. Drivers can ensure correct tyre pressures and avoid unnecessary dead weight (such as unused tool boxes) and drag-causing equipment (such as roof racks). Vehicle engines should be properly tuned with lubricants and filters changed regularly.

Public Transport and Other Strategies

There are a range of practical alternative transport modes to the conventional private motor car, particularly in urban areas. In assessing the effectiveness of these alternatives, the strengths and weaknesses of each situation needs to be considered.

Public transport is usually held to be far more energy efficient than cars, but this is not universally true when load factors, circuitous routes and other issues are considered. During off-peak periods, minivans, taxi vans and various forms of paratransit are likely to be more energy efficient than a poorly-loaded 40-seater bus. Paratransit is a modern update and major improvement over older dial-a-ride concepts and airport shuttle bus services.

In the medium term, conventional public transport does not hold the key to markedly improving the efficiency of passenger transport in New Zealand, although it could make some important local differences. This is because any changes would be made on a small base; patronage levels are low and public transport is a minor energy user compared with private cars. The trend in patronage is generally down, but some areas are experiencing modest increases.

The first step for public transport is to get load factors up, both during peak periods and at other times. This can be achieved by discouraging the use of cars and improving the quality of the public transport service. Means of achieving the latter include assigning buses priority at intersections and along special lanes, and the use of information technologies to provide better schedule reliability and passenger advice on real arrival and departure times.

Light rail has a number of advantages that make it an attractive transport option. It has the potential to be energy efficient and, importantly, to achieve satisfactory patronage levels and run economically in Auckland, possibly Wellington and perhaps one or two other main centres. In terms of national energy use, light rail will make only a small difference, but it could confer important local environmental benefits, especially reduced congestion, and improved energy efficiency for cities that find it a suitable option.

Cycling is another very efficient transport mode. While not all New Zealand cities are well suited to cycling, there is little doubt more could be done to encourage this mode of transport. Christchurch, for example, by virtue of its large area of flat land, has a relatively high number of commuter trips made on cycle (10%) but few by public transport (5%). There is a division between cyclists and planners as to whether the best approach is to try to separate cyclists from motorists or to facilitate better co-existence via traffic calming and education of the two classes of road user. Either approach is likely to be better than dealing with cycling as a transport afterthought.

An exciting development in the United States is the use of neighbourhood vehicles, small light-weight vehicles designed for non-motorway urban running. The concept is being developed out of the experience with the use of golf carts on public roads in Palm Springs. A single or twin in-line seater would be suitable for most urban tasks. If widely adopted, such a vehicle would require less lane width and parking space than conventional cars.

Urban planning has the potential to integrate transport systems and the pattern of settlement and activities in a way that reduces travel demand and/or improves energy efficiency. Urban energy use per capita correlates with population density, although matters such as urban form are also important. Transport energy use in Auckland and Wellington falls between the extremes of the spread-out car dependent cities of the United States and the densely populated, mass transit cities of Europe and Asia.

The urban form that seems to require the least transport energy is one where activities are concentrated at several main centres, reasonably close together, rather than a single dominant central business district. This layout seems to minimise trip distances without creating the need for an excessive number of trips. Ideally, these centres would lie along corridor routes with sufficient urban population densities to make public transport systems well patronised and commercially viable. While radically changing the basic form of our cities is impractical in the medium term, many opportunities arise during redevelopment and urban expansion to improve transport energy efficiency.

The need to travel at all may also be reduced by the use of teleconferencing, telebanking and teleshopping, and the trend towards working from home offices. It is difficult at this stage to be sure that these factors will actually reduce transport demand rather than altering the timing or principal purpose of trips (people working from home may still travel into town for shopping or entertainment).

New Zealand's experience with transport demand management (encouraging public transport or discouraging private car use) has been mainly through providing road priority for buses, such as the busway on Auckland's northern motorway, and parking restrictions, such as the coupon parking scheme in Wellington. Both these types of measures appear to be successful in reducing inner city congestion, which was their primary goal rather than energy efficiency.

Freight Transport

Data on the energy consumption and energy efficiency of air freight services is not readily available. The energy demand of freight services are difficult to separate out from passenger services. Nonetheless, it is clear that air freight is markedly more energy intensive than the other modes but often satisfies special needs, such as speed of delivery, and this makes comparisons with the other modes inappropriate.

There is considerable overlap between the energy efficiencies of road, rail and sea modes. None of these three modes can be said to be universally superior to the other two.

Comparisons have to be made with care and on a case-by-case basis. The full transport system needs to be considered from origin to destination, including all mode changes.

Sea and rail freight have been deregulated and are now on a fully commercial footing. Road freight has been deregulated and studies are underway to check that all road users are paying the full costs of their activities. This is important, because hidden subsidies dilute the effect of fuel costs on an industry's cost structure and reduce the incentives for energy efficient operation. Each mode needs to be made as efficient as possible, and various means are identified in Volume 1 to achieve this goal. In addition, rather than treating modes as alternatives, adopting an integrated approach is suggested.

Road freight efficiency can be improved by increasing load factors, increasing the ratio of payload to gross vehicle weight and reducing vehicle losses, especially aerodynamic drag. The means to achieve these results include:

- freight brokerage systems;
- greater use of lightweight materials;
- possibly the creation of special heavy transport routes to allow an increase in maximum gross vehicle weight; and
- aerodynamic streamlining of truck and trailer units.

The benefits of the latter are well documented, but may need to be better disseminated within the trucking industry.

There have been significant improvements in the energy efficiency of rail freight since 1985. The outlook, however, for the 10 years to 2005 is for little further change. This is because the closure of small branch lines is complete, the benefits of electrifying the main trunk line have been realised and the existing fleet of DX diesel electric locomotives is likely to remain in service. Furthermore, the difficult New Zealand terrain precludes major changes to maximum train size and track alignment.

Total energy use by coastal shipping appears to have fallen since 1990, but a reliable trend in energy efficiency is not available. It is difficult to predict future trends as vessel or engine replacement occurs infrequently and fuel efficiency is only one of several criteria for such investment decisions. Meanwhile, the efficiency of the vessels in service could be influenced by improving load factors and attention to hull and propeller maintenance. In the longer term, the results of research and development into new propulsion may be available. One prototype system converts wave energy into forward movement, reducing power needs by up to 30%.

Volume 2: Highlights

Part 4: Primary Production

The primary production sector includes fishing, farming and forestry and these activities are covered in Part 4. The off-site processing of farm, horticultural and forest products, and fish is covered in Food Processing and Forestry Processing, Parts 5 and 6. Mining, sometimes considered as primary production, is covered in Part 7, Minerals and Manufacturing.

Most of New Zealand's primary production is not energy intensive, and where it is (such as dairying) it generally compares favourably with overseas countries. There is, however, a trend towards intensification of production on suitable land and it is vital that this go hand in hand with good energy management. Although the primary production sector's total energy demand is a small fraction of the national total, around 4% to 5%, energy efficiency in the sector is important in maintaining the competitive advantage and the clean, green image of New Zealand's exports.

The total liquid fuel consumption for primary production and related transport is 430 million litres, or approximately 16,000 TJ/year. This is fairly evenly divided between petrol and diesel. One-half of the diesel is used for off-farm transport, with the balance used by tractors and implements. About 90% of the petrol is used for off-farm transport. Fishing is a major diesel user, with an annual demand of around 3000 TJ. The logging industry consumes over 60 million litres of diesel annually (approximately 2000 TJ), mainly for harvesting (30%) and transport (70%) and a small amount of petrol is used in smaller plant such as chainsaws.

Agriculture is the main user of electricity, at just over 2000 TJ/year. The main end uses for electricity are pumping, water heating and refrigeration.

The energy efficiency focus for dairying is the milking shed. Efficient water heating and milk chilling technologies can be used and integrated. For example, the condensers on the chiller unit can be used to heat water. Attention to basic details such as effective insulation on hot water cylinders and milk vats will pay dividends. Refinements are being made to vacuum milking systems to improve efficiency.

Poultry and pigs are often raised in intensive conditions under shelter, which require efficient heating, lighting and ventilation systems. New lighting and infrared technologies are available that can provide controllable and efficient heat and light. Energy can be saved in extensive livestock systems through attention to efficiency in stock water supply, fodder production and fodder conservation. The latter requires application of the same techniques applicable to arable farming. These include careful tractor selection and proper operation, tillage reduction and effective irrigation. Where crops are chilled or dried on-farm after harvest, the use of natural gas or LPG and electric heat pump technologies and efficient fan systems should be considered.

Energy efficiency in horticulture relies on applying similar principles and technologies to arable farming. A wide range of efficient crop cooling technologies are available. There are some energy efficiency parallels between producing plants under cover, in a greenhouse for example, and intensive pig and poultry production. A major concern is that while most New Zealand greenhouses are less than 10 years old, only about 10% are of an energy efficient double-skinned design. Only about one-third of the balance have some inner plastic liner to help reduce heat loss. The use of artificial light and other means to increase production per square metre of covered space can reduce total energy use per unit of production.

Exotic forest establishment on what was once pastoral land is rapidly expanding in New Zealand. Contrary to popular opinion, the growing and harvesting of exotic forests is more energy intensive than pastoral farming when energy demands over a whole rotation cycle are averaged. It could become even more intensive in the future as harvesting becomes further mechanised. On the other hand, machines enabling whole tree harvesting could mean increased yield of useful products, including waste wood energy sources. There is potential to reduce the energy use by log trucks. Information on relevant technologies is provided in Part 3, Transport, in Volume 1.

There are also opportunities to reduce the energy use in fishing. The vessel and its propulsion systems can be improved, and on-board ancillary equipment such as refrigeration can be made more efficient. Radical propulsion systems using wind or wave energy are being trialed. Techniques that help masters to catch their quota with the least amount of steaming (navigation, fish finding, net monitoring, etc.) also help reduce energy use. The energy sapping drag on trawl nets or other types of gear can also be reduced.

People living in rural areas may be faced with the opportunity and the incentive to produce some of their own energy. A range of technologies are available for remote area power supply schemes (RAPS) to service homesteads, provide electricity for specific remote tasks (e.g. electric fencing) or enable the production of biofuels from farm wastes or special crops. In some cases, biofuel production can be linked to the need for effective waste management, such as the disposal of dairy shed effluent.

Part 5: Food Processing

The total energy use in the New Zealand food system is made up of production (28%), processing (32%), distribution (18%) and preparation (23%). The 32% used in food processing is the focus of Part 5. Food processing uses over 31,000 TJ, or approximately 9.5% of national primary energy requirements. Producing heat for drying purposes is the main energy use in the food processing industry. Oil was once the dominant source of this heat, but has largely been replaced by natural gas.

The major energy consumers in the food sector are the dairy and meat industries. Together they account for around 70% of the total sector energy demand and so receive the most attention in the material presented in Part 5. The main technologies and methodologies for improving the use of energy in the New Zealand food processing industry are:

- considering the fundamental technological requirements of processes and matching these to the energy supply (e.g. variable speed fans in meat freezing);
- using efficient heat transfer and reuse, such as direct firing of driers, adopting mechanical recompression in evaporators and applying pinch technology;
- optimising insulation in both hot and cold applications and paying attention to other well understood but easily neglected practices; and
- exploring new technologies such as electro-technologies, the use of superheated steam and low temperature heat pump dehumidifier drying.

Applications of new technologies in food processing are outlined in Part 5, while the underlying principles of electro-technologies (including heat pumps) and heat transformers are described in Part 8, General Energy Efficiency Technologies.

Greater use of mechanical vapour recompression, membrane separation, cogeneration and conversion from steam pressurised hot water systems would improve energy use in dairy processing. Better heat recovery would benefit the meat industry; for example, the use of supercritical refrigerants such as CO_2 would enable effective heat recovery from chiller condensers. The use of variable speed electric motors to drive plant such as fans would also be helpful. Management practices (e.g. better scheduling of refrigeration compressors) can also save energy.

Part 6: Forestry Processing

The New Zealand log harvest is slightly less than 16 million m^3 per year. Approximately one-third of the wood volume goes into pulp and paper manufacture, and log and chip exports account for another third. The next major use of wood is for sawn timber (about 2.5 million m^3). Plywood and reconstituted panel board manufacture make up the balance. The energy use in local forestry processing is covered in Part 6.

The forest processing industry is already a major energy user, consuming over 50 PJ per year and reducing the proportion of log and chip exports by further processing in New Zealand could dramatically increase the energy demand by this sector. The largest source of this energy is pulp residue and waste wood (about 23 PJ). Approximately 25% of the consumer energy demand is for electricity (approximately 12 PJ) with cogeneration providing about one-tenth of this. Natural gas and geothermal energy are the next major energy sources.

Forest processing uses almost 10% of New Zealand's total power generation, which makes this sector the second largest industrial electricity user, after aluminium production. Pulp and paper manufacture uses over 80% of the electricity (and heat) consumed in forestry processing. New Zealand produces similar amounts of pulp and paper by mechanical (670,000 tonnes) and chemical or kraft (700,000 tonnes) processes. The kraft process is heat intensive, but obtains much of its requirements from burning pulping residues. Mechanical pulping is electricity intensive and there are commercial opportunities for the generation of this power from cogeneration using wood waste (e.g. bark and contaminated chips).

New Zealand kraft mills compare favourably with overseas mills of the same era. There is a trend for increased energy use in paper manufacture due to higher production rates and higher product quality. In a modern mill, this can be countered by energy efficiency. Modern Swedish and Finnish mills, for example, require less total energy than older mills, are more than 100% self-sufficient in heat (they can export heat) and 80% self-sufficient in electricity. The technologies that have made this possible include extended delignification, increased tree utilisation, reduced evaporation, the use of biomass in the lime kiln and greater cogeneration.

Retrofit technologies that could improve energy utilisation in New Zealand kraft mills include batch digester energy recovery, commissioning new continuous digesters, using higher consistency (less water) pulp handling, low odour conversion of recovery boilers, cogeneration and other efficient plant (such as mechanical vapour recompression and infrared drying).

Mechanical refiner mills should be largely self-sufficient in heat by using energy recovery from refiner flash steam. Even with the old groundwood process, up to 30% of the input electricity can be recovered as heat. With possibly one exception, New Zealand mills do not take full advantage of the technical potential for refiner energy recovery. A variety of technologies are under development to reduce the electrical input to the refiner pulping process.

Energy efficiency in sawmilling can be improved by using better saw design and operation to increase timber yield. Kiln drying of timber is a growing energy intensive activity. The use of low-temperature heat pump drying, mechanical vapour recompression and better fan systems could mitigate this trend. It may be possible to improve plywood energy efficiency by using closed thermal fluid (hot oil) heating systems rather than steam, with its attendant losses. The manufacture of medium density fibreboard is similar to mechanical pulping in that refiners are used to grind the wood. Once again, there appears to be an opportunity for heat recovery that is not presently being realised.

Part 7: Manufacturing and Minerals

This sector uses around 20% of New Zealand's total consumer energy. It divides naturally into a low-energy using manufacturing group and the high-energy minerals group, which consists of metal refining, cement production, clay and glass industries. Aluminium, steel refining and other members of the minerals group account for nearly 60% of the total energy used by the manufacturing and minerals sector. Steel and cement use almost all of the sector's coal supply and about 40% of the total fuel supply. Aluminium smelting accounts for two-thirds of the sector's electricity supply.

Heat is the main energy need for the manufacturing group and natural gas is the dominant fuel source. Most of the energy consumed in the chemical industries and in metal fabrication is used to produce high grade heat (e.g. in kilns). The textile and leather industries mainly use fuels for intermediate grade heat (e.g. steam from boilers). Electricity use makes up about 25% of the manufacturing group's energy supply and nearly all of it is used for motors driving pumps, fans and other machinery.

Specific technologies applicable to the manufacturing and minerals sector, and other sectors as well, are outlined in Part 8, General Energy Efficiency Technologies. Part 7 concentrates on a number of general principles relating to targeting and monitoring, and good housekeeping. It also provides some case studies relevant to the energy intensive minerals group.

Target setting is emphasised. The starting point is to establish the current energy use, or T0. The next step is to set T1, the target from quickly implemented measures such as good housekeeping. The next target is T2, which represents the long-term savings from investment in new technology. Finally, there is a target represented by state-of-the-art plant and processes, T3. Methodologies for setting targets are discussed and sector studies play an important role in this respect. Such studies enable benchmarking and analysis of the performance of particular plant to be compared with the industry norm and best achievers. They also provide a guide to the means of improving the energy performance of under-achieving plants.

The establishment of an energy monitoring and targeting (M&T) programme as part of an integrated approach to target setting and achievement is discussed. Staff involvement and the need to assign responsibility, ideally by appointing an energy manager, is emphasised. The use of computers can significantly improve monitoring and analysis of energy use data. The benefits of a M&T system are significant; for example, a survey of 700 UK sites with M&T systems showed that they are cheap to install and operate, provide average energy savings of around 8%, save utilities (e.g. water use), increase productivity and reveal subsequent ways to save further energy and provide additional benefits. Payback periods were less than two years.

The first round of energy savings comes from good housekeeping. The basic principles of good housekeeping are to ensure that the appropriate form of energy gets to where it is needed in the right amount, at the right time and with minimum loss. Good plant maintenance, correction of leaks (e.g. compressed air lines), adequate insulation and lagging, turning plant off when not needed, etc. all contribute to good housekeeping.

Part 8: General Energy Efficiency Technologies

Part 8 is not specifically linked to any economic sector. Instead, it outlines a range of energy efficiency technologies that find application in buildings, transport, and primary and secondary industries.

Part 8 starts by emphasising efficient generation, use and reuse of heat. There are chapters covering heat recovery technologies, kilns, ovens and furnaces, heat pumps and heat transformers, and cogeneration. A chapter on pinch technology provides a methodology for correct design heat utilities and recognising opportunities for heat recovery. Precise automatic control of utilities plays a vital role in the quality control for many manufacturing processes. It can also be a powerful tool for energy efficiency.

Electricity can be used directly as a heat source, but arguably it provides best value when used in lighting and motors. Technologies for general illumination are well covered in Parts 1 and 2 and are not repeated here. Efficient motor technologies are identified. In many applications, an efficient electric motor will pay for itself in a few years.

The characteristics of pumps, fans and compressors and associated utilities (e.g. water supply) are discussed and the implications for electric motors is discussed. The key to efficiency is maintaining a good match between the motor, the machinery it is driving and the utility needs at all times. Variable speed drives can achieve this and are recommended wherever system needs fluctuate.

The final chapters in Part 8 cover a range of electro-technologies that have the potential to replace conventional heating technologies. Often steam or hot air is used in curing and baking processes. The kilns or ovens have to be heated along with the item being processed. In some cases, only a component requires heat treatment. Electro-technologies enable heat to be precisely directed to where it is needed with minimum spillover to the rest of the item or its surroundings. In fact, electro-technologies question the need to use heat at all and open up the possibility of changing the process (e.g. using ultraviolet paint curing instead of baking). The electro-technologies covered are dielectric heating, induction heating and melting, infrared heating, and ultraviolet curing.

Part 1

Domestic Buildings

Contents of Part 1: Domestic Buildings

Chapter 1
Domestic Sector Overview

1.1 Energy Use in Homes

Energy use in the domestic building sector is defined as the energy used by people living in private homes, rented homes, apartments and flats. It does not include energy consumed in commercial accommodation such as hotels, nor does it include the energy used in private transportation. On a national scale, the domestic sector uses 13% of the total energy used in New Zealand (see Figure 1.1), but energy efficiency in domestic homes is important because of the unique structure of the domestic sector — it is the only sector that serves as a base to everyone and a workplace to some.

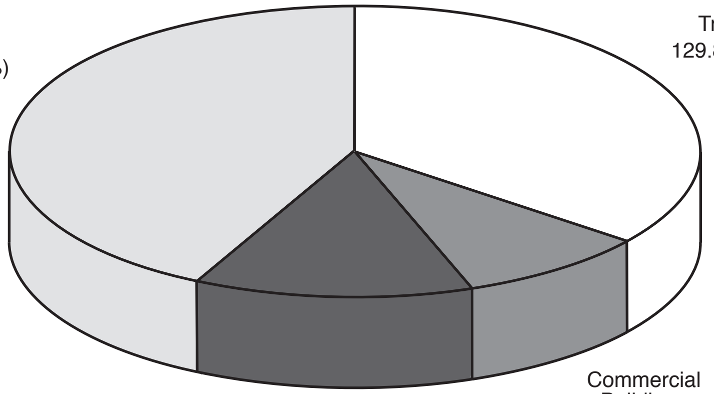


Figure 1.1: Total amount of energy used in the different New Zealand sectors (Massey University, 1992)

The domestic sector has a large impact on New Zealand's electricity consumption. It accounts for 37% of the total electricity consumed in New Zealand, making it the second largest user behind the industrial sector at 42%. Reducing electricity consumption through the adoption of energy efficient technologies will reduce the threat of future electricity shortages and delay the need to build further power generation stations.

On a smaller scale, a house is the largest single investment for most people. The extra costs incurred in making a house energy efficient are compensated by lower running costs. Both homeowners and occupants need to be aware of the importance of energy efficiency. The Ministry of Commerce (1991) claims that homeowners can reduce their current energy consumption by 60% by using energy more efficiently.

Figure 1.2 illustrates the types of energy used in the domestic sector. After removing electricity, 29% is accounted for by all other energy types, of which wood is the largest contributor. Gas and coal demand is 7%, although gas demand has increased considerably over the last 10 years and this increase is expected to continue. Coal demand, on the other hand, is continually decreasing in proportion. Other types of energy used include oil and LPG.

At present, the average homeowner spends a significant proportion of the household budget on buying energy, whether it be electricity, gas or solid fuel. Figure 1.3 illustrates that almost three-quarters of the household energy bill goes into space heating and providing hot water and these two areas are where considerable energy savings can be made. The remaining 24% is loosely categorised as appliances, which includes lighting, cooking, washing, etc.

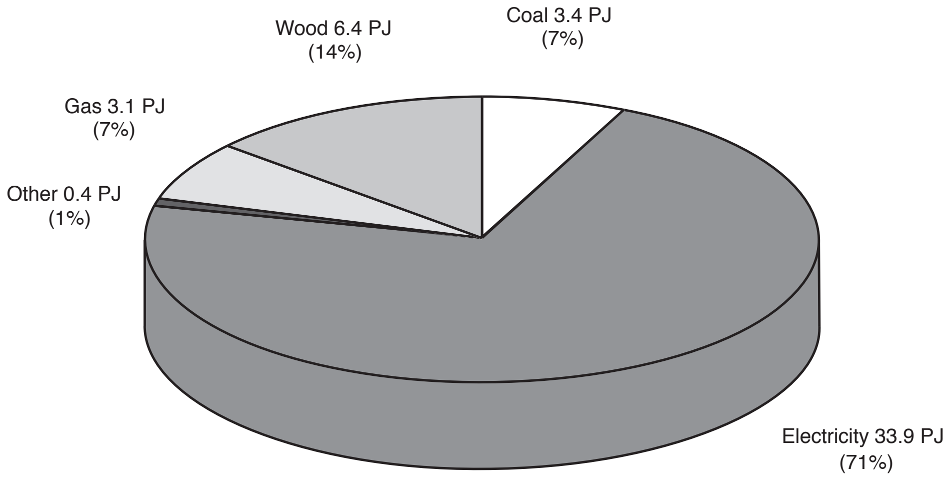


Figure 1.2: Domestic energy sector demand — 1991 (Massey University, 1992)

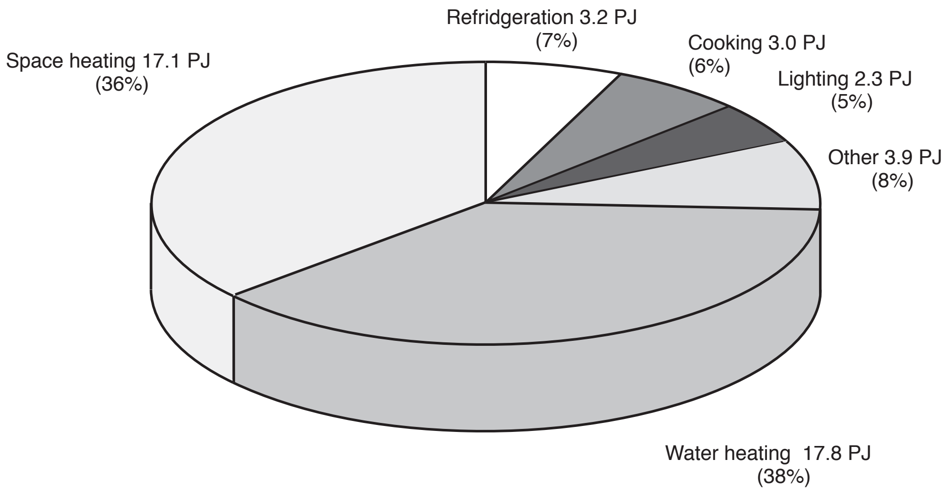


Figure 1.3: Domestic sector energy uses — 1991 (Massey University, 1992)

The distribution of energy types across the various energy uses is illustrated in Figure 1.4, which clearly shows the dominance of electricity in the domestic sector appliance and hot water end uses. At present, 84% of cooking appliances and 87% of hot water cylinders use electricity.

Space heating uses a variety of energy forms, although at 40%, electricity is still the largest source. A similar amount of energy is used from wood (35%), while coal is used for 18%. Gas is used for nearly 8% of space heating and is also used in cooking (13%) and hot water heating (8%). Coal and wood are used for a very small percentage of hot water heating and cooking.

If energy efficiency is to become a priority in the domestic sector, the cost implications must be beneficial in the long run, and people must realise the savings potential and act on it. Any extra costs for insulation, energy efficient lighting and other measures should quickly be repaid from energy cost savings.

There are three major factors that can affect the energy efficiency of a home:

- the first is the home itself — the design, materials and quality of construction and insulation;
- the second factor is the type of appliances used for space heating, water heating and other activities (clothes dryer, lighting, etc.); and
- the third factor is the way the home is used by the homeowner and occupants.

These three main issues are dealt with in turn.

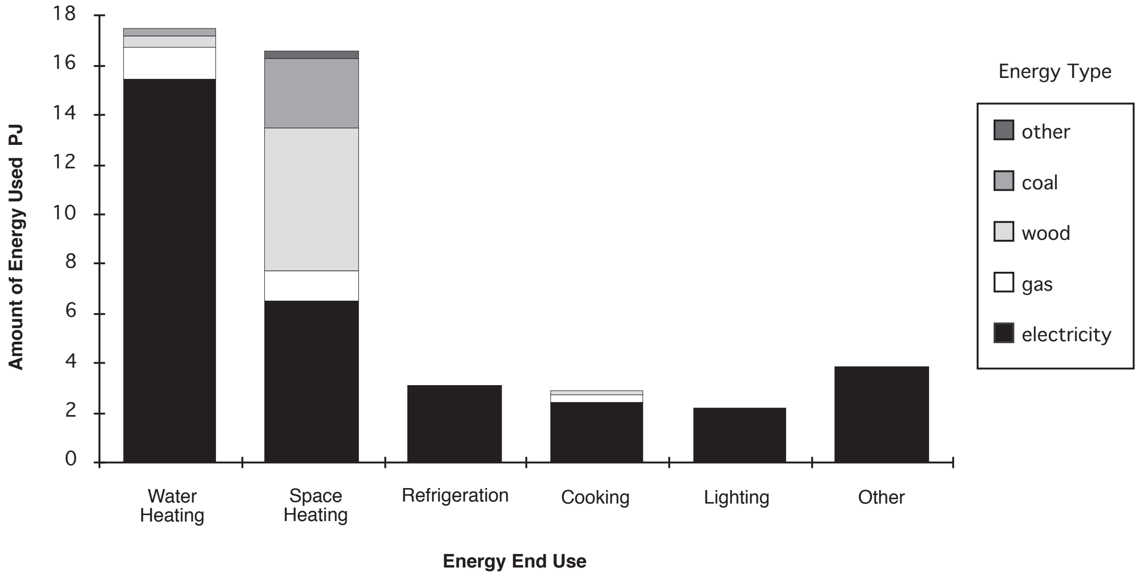


Figure 1.4: Distribution of energy type (Massey University, 1992)

1.2 Energy Efficient Homes

For a home to be energy efficient, it has to be designed with this aim in mind. It is important that the site chosen has good natural lighting and that the home is placed on the site to gain maximum benefit from the sun's energy. Construction materials and their properties are important. Without insulation, any other design decision to make a home more energy efficient would be wasted because the home would not have the ability to retain heat. The final, but probably the most important, factor in the construction of a home is the quality of workmanship. If this is inadequate, the materials used in the building will not achieve their full potential. This is especially true with the installation of insulation.

Insulation

The relative proportions of heat loss from an uninsulated house in winter are shown in Figure 1.5. Thermal insulation reduces the rate of heat lost and hence the amount of energy required to heat a house. It is a barrier that restricts the amount of heat flowing through walls, ceilings and floors of a house, hence preventing heat from escaping and being wasted. The Ministry of Commerce (1991) states:

> *There is little doubt that for the majority of New Zealanders, the major method by which space heating energy demands can be reduced is to fit more insulation. Even new houses in New Zealand are poorly insulated in comparison with houses in most other developed countries. This lack of insulation makes New Zealand houses hard to heat and the resulting cold and damp dwellings may contribute to the fact that New Zealand stands out amongst developed nations with a higher death (mortality) rate in winter, particularly in the very young and the very old. There is also little doubt that many existing New Zealand homes are not heated to the Health Department minimum recommended level of 16°C.*

Thermal insulation also has other positive effects, such as improved indoor comfort levels, reduced risk of mildew growth and a healthier environment. Since 1977, New Zealand has required all new houses to meet a minimum level of insulation set down in the thermal insulation standard (NZS 4218P:1977). NZS 4218P has been considered for reissue twice (in 1987 and 1990), but no new standard has yet proceeded beyond draft stage. The New Zealand Building Code (BIA, 1992) currently includes this standard as an acceptable solution for meeting the H.1 energy efficiency requirement for domestic housing.

During the period 1 April 1978 to 1 April 1993, 309,000 houses were built with the requirement to be insulated to the levels given in NZS 4218P. The total number of occupied dwellings in New Zealand reported by the Census of Population and Dwellings (Department of Statistics, 1991) in 1991 was 950,646 for separate houses. This suggests that only about 30% of New Zealand houses currently meet the present standard.

However, in 1983 an investigation was carried out into the extent of compliance with the NZS 4218P (Isaacs and Trethowen, 1985). It found that of 63 houses tested in Auckland, Wellington, Christchurch and Dunedin, 43% complied fully, 30% complied partially or were near-misses, while 10% of the houses failed to meet the requirement of the Standard (the balance could not be accurately assessed). It was concluded that the thermal efficiency of houses had been significantly improved by the application of the Standard.

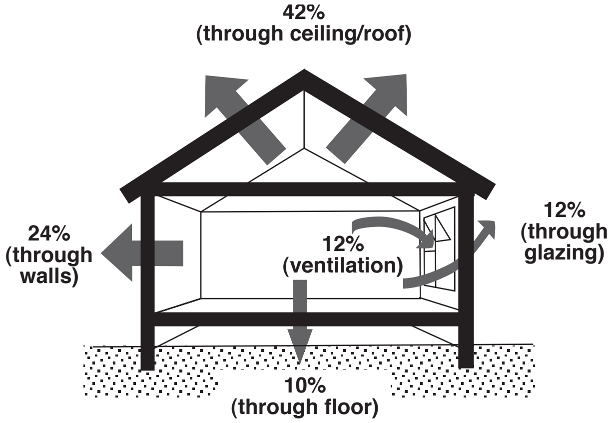


Figure 1.5: Heat loss paths in house (BRANZ, 1992)

Figure 1.6 shows how changing the thermal insulation reduces the purchased heat energy requirements needed to achieve a typical regime of indoor comfort (the benefit of insulation increases further if 24 hour comfort levels are required). It illustrates that increasing envelope thermal insulation reduces heat losses and increases the relative importance of useful gains, namely free heat from internal gains (such as refrigerator coils) and solar heating. Further information on insulation is provided in Chapter 4 "Insulating New and Existing Homes".

Mass

The mass of a building influences the thermal performance of the envelope and, therefore, the resultant thermal environment within the building, by absorbing and releasing thermal energy. It can be used as a heat store or to iron out swings in ambient temperature. Too much mass can be a disadvantage, but traditionally in New Zealand there is very little effective mass in domestic buildings. Typical materials used as a thermal storage medium are masonry, brick and concrete.

The most common use of mass in New Zealand houses is in concrete slab floors. This has become popular in recent years as it is often cheaper than the traditional suspended floors. The approximate cost of a concrete slab floor for a residential building is currently \$46/m^2, and for a timber suspended floor with a concrete perimeter wall, timber piles, bearers, joists and particle board flooring it is in the region of \$56/m^2. These figures are for a residential home built in Wellington (Page, 1994).

Thermal storage is most effective when it absorbs excess heat during the day and releases it at night when the indoor temperature is lower. For this reason, the advantages of thermal storage tend to be largest in climates with large day/night temperature swings or where the daily temperature extremes are large. Thermal storage is best arranged so that it is insulated from outside and in good thermal contact with inside spaces. Insulation, such as carpet on a slab floor, reduces the rate that heat can be both added to storage by the sun and extracted later at night for space heating. The issues involved in placing mass for thermal storage in homes are covered in Chapter 3 "Importance of Thermal Mass". Thermal mass is critical to the effectiveness of passive solar space heating. Refer to Chapter 2 "Solar House Design" for further information.

Glazing

The heat loss through uninsulated glazing can be as much as ten times the heat loss through the same area of insulated wall. Glazing does, however, allow heat from the sun's energy into a house, and with careful design this can exceed the winter time heat losses from windows. The easiest and cheapest way of reducing heat losses at night and on cold cloudy days is with drapes. To be effective, these must fit tightly to the perimeter of the window so as to form a pocket of trapped air.

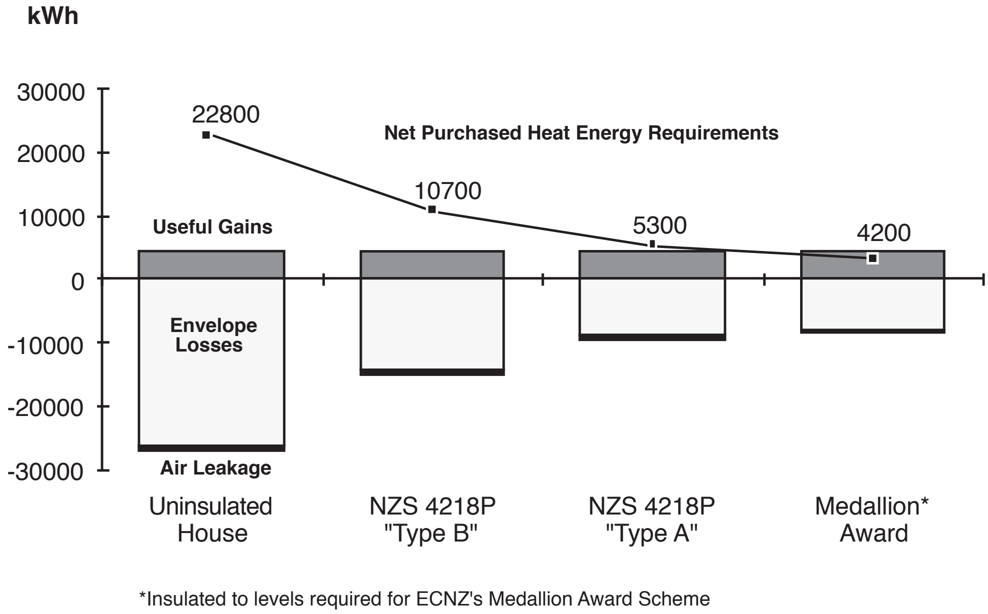


Figure 1.6: Annual energy consumption (kWh) (Isaacs, 1993)

A more effective way of forming a pocket of air and halving the heat losses through windows is with double glazing. This is still relatively uncommon in New Zealand, but with more widespread use there will be some potential for cost reductions. Double glazing also provides other benefits, such as eliminating condensation and reducing noise transmission. Double glazing is currently 50% more expensive than single glazing, at an approximate cost of $270/m^2 of window area in Wellington (Page, 1994). Information on double glazing technologies is presented in Chapter 5 “Efficient Windows and Glazing”.

To make the most of solar energy gains, the orientation of windows around a building, their size and the amount of mass in a house all need to be considered. The orientation of windows in relation to the path of summer and winter sun determines the solar gains and their timing during the day.

> *In the winter, the greatest heat gains come from north facing windows. East and west facing windows can lose more heat than they gain in the winter months and are sources of overheating in the other three seasons.*
>
> *New Zealand Engineering*, August 1986: D Breuer

Even southern facing windows collect some solar heat, even in winter, but the gains are small compared with losses. Overheating can be a problem where large areas of glass are unshaded from direct summer or winter sun. The role of glazing in passive solar heating is covered in Chapter 2.

Ventilation

Ventilation has a role in removing excess heat in summer from living areas as well as removing moisture and a range of indoor contaminants. The traditional way of ventilating homes is to open windows. This has become less favoured because of concerns for security and because current lifestyles tend to mean that houses are left unoccupied throughout much of the working day. Air infiltration driven through cracks and gaps in the building shell by wind pressures is another source of ventilation. In older houses, air infiltration rates were generally sufficient to control indoor contaminants, but the trend in new houses is towards more airtight construction. For these reasons, provisions for ventilation will have to be more carefully considered in the future, and passive and active ventilation systems will be more commonly used in New Zealand. There is a trade-off between the level of home heating and ventilation for moisture control. Ventilation also means loss of warmed space air. Energy efficiency means optimising these trade-offs and ensuring both heating and ventilation systems are themselves efficient. Further information on ventilation is provided in Chapter 6 “Ventilation in Homes: a Critical Issue”.

1.3 Appliances

As manufacturers become more aware of the need for energy efficiency, appliances are being made more efficient all the time, whether they are used for heating the home, hot water, or the general appliances used in day-to-day life. These more energy efficient appliances will only have a national effect when old appliances are replaced with new ones. Meanwhile, there are things householders can do to improve energy efficiency by properly maintaining and operating equipment. Issues related to the energy efficiency of appliances other than space and water heaters (refrigerators for example) are covered in Chapter 14 “Appliances”. This chapter discusses the role of minimum energy performance standards for appliances and a methodology for setting such standards.

Space Heating

The space heating energy required to heat a house depends on many factors relating to building design, climate and occupancy. These include:

- the level of insulation in exterior walls, ceiling and floors;
- the area and thermal efficiency of windows;
- the thermal mass incorporated within the insulated envelope;
- ventilation;
- window solar gains;
- casual heat from internal gains (heat from people, lights, hot water cylinders etc.);
- the outdoor climate;
- the indoor temperature maintained by the occupants.

Heat loss through the envelope is related to the outdoor temperature — the colder the average outdoor temperature the more space heating required to heat a building to the same level. This is shown in Figure 1.7, where a cold climate is represented by a high degree-day level. The graph in Figure 1.7 was obtained by using PC-ALF (Bassett et. al., 1993) and modelling a simple 100 m^2 house in several locations with differing degree-day totals. A degree-day total is defined as the sum of differences between each day’s temperature and a reference temperature for a given period of time. PC-ALF uses a degree-day reference temperature of 15˚C and assumes a constant indoor temperature of 20˚C over the winter months of May to August. The modelled house was uninsulated with timber stud walls and weatherboard linings, a plasterboard ceiling with corrugated galvanised steel roofing and a suspended wooden floor.

Space heating is a large topic and is dealt with in four chapters; Chapter 7 “Space Heating Technologies” provides an introduction, while the other chapters deal with the main fuel types — Chapter 8 “Electric Space Heating”, Chapter 9 “Solid Fuel Heating” and Chapter 10 “Natural Gas Heating”.

Hot Water Heating

Water heating accounts for approximately 38% of energy demand in an average domestic dwelling. There are a number of ways of reducing the amount of energy used to heat water from fixing dripping hot water taps to replacing an old cylinder with a more efficient one.

Many existing hot water cylinder thermostats are set around 75˚C, which is too hot for the water to be used directly. There are also safety considerations (e.g. ACC and Plunket 1990). Reducing the temperature to a safer level will not only prevent many accidents but will make the hot water cylinder more efficient because less energy is required to heat the water to its maximum temperature. The heat loss is reduced since the water is stored at a temperature close to that at which it is to be used.

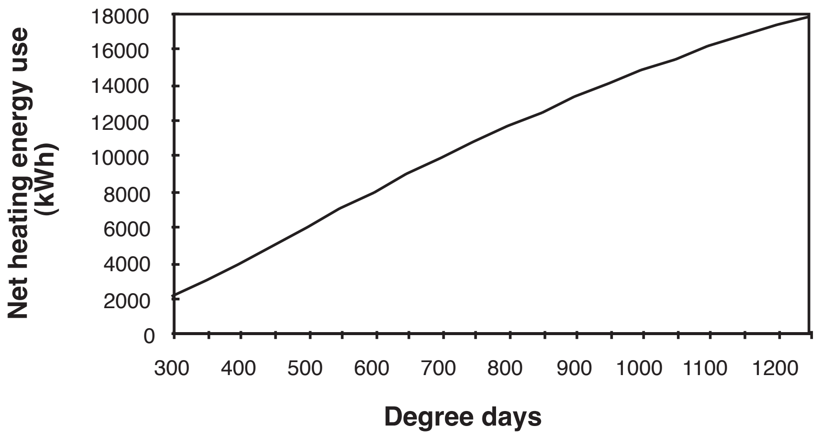


Figure 1.7: Space heating required

It is also important that the water is not stored at a temperature lower than 55˚C as bacteria such as *legionella* may multiply at lower temperatures.

The second consideration for a homeowner is the capacity of the cylinder, essentially whether there will be enough hot water for the daily household routine. The larger the cylinder, the greater the standing heat losses (standing heat loss is the amount of heat lost through the cylinder to the air outside). It is these losses that enable people to air clothes in the hot water cupboard. Cylinders with better insulation are required to reduce these losses.

Some people have the hot water cylinder thermostats set high because the cylinder is too small to supply all their needs. In this case, a tempering valve on the outlet should be installed to reduce the scalding risk.

There is currently no mandatory requirement for the level of insulation of hot water cylinders. However, there are voluntary standards that include thermal performance levels or minimum standing losses for electric cylinders.

Figure 1.8 illustrates the allowable annualised standing heat loss for a 180-litre cylinder under standard conditions and the level of insulation (R value) according to the appropriate New Zealand standard requirement. It shows that there has been a steady decrease in annual heat loss since the introduction of thermal insulation for electric hot water cylinders. The highest efficiency cylinder, NZS 4602:1988 Type A cylinder, shows a 37% reduction from the NZS 4602:1976 version.

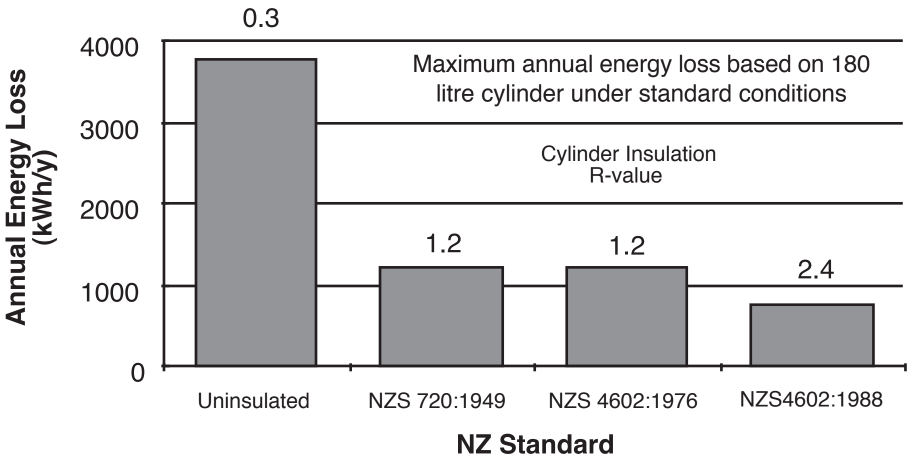


Figure 1.8: Electric hot water insulation standards (van der Werff, 1993)

EDA's "WaterMark" system grades cylinders according to their level of insulation. This system has three grades A, B, and C, where the C grade is a basic cylinder and the A grade is deemed super-efficient. By installing an A grade cylinder, a homeowner pays less for hot water as standing heat losses are reduced. The EDA gives the following as an example:

> *A 180-litre A grade cylinder will deliver 11,000 litres more hot water (at the shower at 41˚C) each year at no extra cost in comparison with a 180-litre B grade cylinder. By the same performance measure, the difference between a 180-litre A grade cylinder and 180-litre C grade cylinder is 17,000 litres more each year at no extra cost.*

At present, it is not mandatory to have an NZS4602:1988 Type A cylinder and there has been no study to find out the percentage of each type of cylinder currently in use in all New Zealand households or what the replacement rate is. For households with electric cylinders that are not A grade, wrapping the cylinders with an insulating blanket would improve the efficiency to a similar level. Insulating the first metre of the hot water outlet pipe with felt lagging or split tubular foam plastic would also prevent further heat losses.

There is little information on the standing losses of gas cylinders. Unlike electric cylinders, they have no heat loss grading or standard. There is a market trend towards the use of instantaneous gas and LPG heaters with excellent water temperature control. Studies indicate that these are slightly less efficient than electric cylinders on an end-use basis (except at low loads when the situation is reversed), but much more efficient when electricity generation is considered.

Chapter 11 “Domestic Water Heating” provides detailed information on electric, gas and solid fuel water heating.

Solar Water Heating

Solar water heating uses the sun’s energy, which is free (apart from the capital cost) and ecologically sound. It has a useful role in improving the energy efficiency of homes by reducing water heating bills and the amount of electricity, gas or solid fuel used by the household. It involves investing in technology that saves other fuels, but it is not cheap to install. There is often a lengthy payback time, which is arguably one of the reasons for the small uptake of solar water heating.

Conventional solar water heaters receive the sun’s energy through metal collector panels. The heat is transferred to water carried in tubes that are part of the panel, and circulating pipes carry the heated water to the hot water cylinder. The water can flow naturally (thermosyphoning) or it can be pumped. A good panel can convert up to 75 percent of the energy it receives into hot water.

Consumer Number 309 (September 1992) states:

> *A 1990 University of Canterbury research report says the “average” household uses 3500-4500 kWh of energy for water heating per year. DSIR studies have shown a good solar water heater can save an average of 2200 kWh per year, approximately half the average amount of energy used. Some of the more recent systems claim much greater savings than shown by the earlier DSIR tests.*

BRANZ appraisal certificate number 166 (1988) states:

> *Solarhart Solar Water Systems can, on average, reduce electrical energy use for heating water by 50-75 percent.*

Solar water heaters obviously require sunlight to collect the sun’s energy. Most areas in New Zealand average around 2000 sunshine hours (New Zealand Meteorological Service, 1983). However, solar heating can’t be entirely relied upon, especially in the winter months. Solar water heating, therefore, needs to be coupled with some form of energy, whether it be electricity, gas or solid fuel. Chapter 12 “Solar Water Heating” describes conventional and new solar water heating technologies.

Efficient Shower Heads

Consumer Number 314 (April 1993) says:

> *In showers, line flow restrictions or low-flow heads save energy — as can shorter shower times and taking showers instead of baths ... For a family of four a shower can account for at least*

> *two thirds of the total hot water consumption, costing around $250 in power bills per year. If the shower uses 12 litres of water per minute, reducing this to eight will save $80 - $90.*

Reducing the amount of water used is another way efficiency in heating water can be improved. A low-flow shower head may cut the hot water section of a household's power bill by a fifth or more, according to *Consumer*.

Other Appliances

For a short time the Ministry of Commerce promoted a voluntary appliance labelling scheme (*Consumer* number 318, August 1993). The scheme was the same as that used in those states of Australia that had compulsory labelling. The scheme involved testing appliances and rating them according to how they compared with a six star scale. The label showed the rating and also the annual energy use (kWh) indicated by the tests. This information helped consumers to discriminate between appliances on the basis of energy efficiency. The main appliances labelled in New Zealand were refrigerators, freezers and clothes driers. Some appliances for sale in New Zealand still carry these Australian labels, but appliance labelling is not actively promoted here at present. The future of appliance labelling is under review by EECA.

Although new appliances are more energy efficient, the number of appliances per household is increasing, hence more energy is being used. According to Wright and Baines (1986), the overall amount of appliances per household will increase by 6.5% from 1985 to the year 2000. The appliance with the largest predicted increase was the microwave oven (55%), then dishwashers (17%) and TVs (15%). A newly emerging appliance growth area is dehumidifiers. The only appliance with a predicted decrease was the freezer, but the fridge/ freezer increase compensates for this. Often an appliance is replaced and retired from its main duty but kept on for a secondary purpose where it continues to use energy (e.g. an old refrigerator may be relocated in the garage to store beer, etc.). As mentioned earlier, further information on appliances is given in Chapter 14.

Lighting

At present, 5% of domestic energy is used for lighting. Most New Zealand homes use incandescent light bulbs, which require up to five times more energy than fluorescent tubes. Wright and Baines (1986) state that, according to major distributors, fewer than 5% of residential lights are at present fluorescent. They estimated the annual electricity use for lighting was 700 kWh/yr made up of:

- kitchen area lights 275 kWh/yr (40%);
- other main living area lights 240 kWh/yr (34%); and
- remaining household lights 185 kWh/yr (26%).

The most promising recent technological development in energy efficient lighting is CFLs (compact fluorescent lamps), which are designed to have a look similar to incandescent bulbs. CFLs are five times more efficient to run than incandescent bulbs and last up to eight times longer. The light quality, output, size and shape of these fluorescents have improved remarkably in recent years and they can effectively compete with the standard incandescent light bulb.

However, CFLs, despite being the way of the future, may have draw backs. *Consumer* Number 307, August 1992 states:

> *Used correctly, these bulbs will certainly save power — and every little bit helps. But consumers should be wary of expecting too much. Compact fluorescent bulbs have limited use and, for many people, the money they spend in order to save on these bulbs could be better used elsewhere.*

It continues:

> *You need to run them for at least four hours at a stretch to get the promised savings — and the more you switch them off, the shorter their life becomes. Nor do they work with dimmer switches.*

In addition, CFLs are not shaped the same as incandescent light bulbs and many will not fit into existing light sockets or shades, or may look out of place, and they are much more expensive.

In future, CFLs may become more widely used as their cost falls and a better range of light fittings becomes available. Chapter 13 "Opportunities in Domestic Lighting" looks at the application of efficient lighting technologies.

Behaviour Changes

Reductions in a household's energy use can be achieved by a multitude of behavioural changes and better household maintenance. For example:

- having a shower instead of a bath;
- sharing bath water;
- fixing leaking hot water taps;
- not running the hot tap to waste until it gets hot, then filling the sink/bath and adding cold water;
- closing curtains and drapes as night falls and opening them in the morning;
- simply putting lids on pots can greatly reduce the energy used in cooking;
- using crockpots, pressure cookers and microwaves to their full advantage as they require less energy than conventional ovens; and
- periodically cleaning the condenser unit at the back of the fridge.

However, such behavioural changes need constant reinforcement to produce consistent energy savings. There has been no study that has monitored behavioural habits in respect to energy efficiency and the possible savings by having energy efficient habits in New Zealand.

1.4 Legal Requirements

There are two ways to improve energy efficiency in the domestic sector. The first is to educate people and make them aware of the potential savings that can be made for themselves as well as nationally. The second way is through the New Zealand Building Code and Standards and other forms of regulation (such as minimum energy performance standards for appliances). This section compares the New Zealand Building Code requirements, set out in Table 1.1, with standards from other countries.

As already noted, New Zealand only has a thermal efficiency requirement for housing. There are no code requirements for either water heating (although standards are available) or appliances (the current labelling scheme is voluntary) as indicated in Table 1.1. Section H.1 of the New Zealand Building Code and Approved Documents (BIA, 1992) allow either a prescriptive standard, NZS 4218P:1977 to be followed or a performance-based standard using the ALF (Bassett et. al., 1993) method for achieving the required domestic thermal efficiency performance level.

The ALF method estimates how much energy would be used under a standard set of conditions — notably 24 hour heating to 20°C of all occupied spaces. It makes allowance for orientation, infiltration, thermal insulation and the effect of mass storing heat during the day and releasing it by night. The estimated heating energy is used to calculate a BPI (Building Performance Index), which is the amount of energy needed to maintain a building at a constant internal temperature, measured per m^2 of floor area and per degree-day for the period 1st May to 31st of August. This performance-based method allows more flexibility than the prescriptive standard NZS 4218P: 1977, the key requirements of which are set out in Table 1.2.

Figure 1.9 illustrates that New Zealand's thermal performance levels are lower than almost all other countries (despite many of those allowing a maximum amount of glazing in their performance levels). However, differences in climate must be taken into account.

Functional Requirement	Buildings throughout their lives, shall have provision for ensuring efficient use in controlling indoor temperature when that energy is sourced from a public electricity supply, or any other depletable energy source.
Performance	H1.3.1 The building envelope shall be constructed to ensure that the building performance index shall not exceed 0.13 kWh.
Verification Method	The building performance index for housing may be verified by following the procedures of the ALF Design Manual.
Acceptable Solution	Construction conforming with NZS 4218P Clause 2 is an acceptable solution for satisfying the Performance of NZBC H1.3.1.

Table 1.1: NZBC Section H1 housing energy efficiency requirement

Part of thermal envelope	Combinations of minimum standard total thermal resistances (m^2 °C/W)			
Type A roofs	1.9 2.6 3.0			
Type A walls	1.5 1.2 1.0			
Floors	0.9 0.9 0.9			
Type A roofs		1.9 2.6 3.0		
Type B walls		0.8 0.7 0.6		
Floors		0.9 0.9 0.9		
Type B roofs			1.5 2.0 3.0	
Type A walls			1.5 1.2 1.0	
Floors			0.9 0.9 0.9	
Type B roofs				1.5 2.0 3.0
Type B walls				0.8 0.7 0.6
Floors				0.9 0.9 0.9

Table 1.2: NZS 4218P Prescriptive insulation levels (Type A includes light timber frame construction and certain panel systems that contain a suitable cavity. Type B is construction not regarded to be Type A.)

An international comparison (Isaacs et al., 1994) of energy efficiency requirements for housing compared codes in New Zealand, Victoria (Australia), the United Kingdom and California. It showed that the New Zealand Building Code has lower values than these other countries

Table 1.3 illustrates the differences in the prescriptive standards, once again showing that New Zealand's minimum levels are low. Both the United Kingdom and Californian codes include glazing requirements. If double glazing is used in the United Kingdom, a larger percentage of the floor area is allowed for windows. The California code requires insulated glazing units.

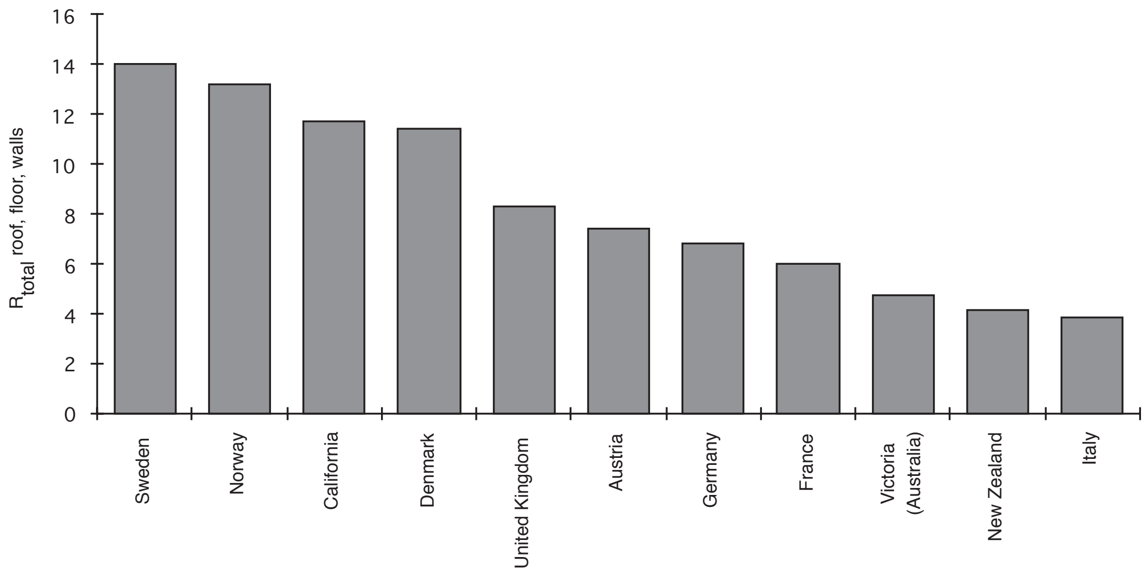


Figure 1.9: Total thermal insulation requirements — a comparison of countries (Isaacs et. al., 1994)

SUMMARY TABLE	New Zealand	State of Victoria	United Kingdom	California
Roof	R-1.9	R-2.2	R-4.0	R-5.3
Walls	R-1.5	R-1.7	R-2.2	R-3.3
Floor	R-0.9	R-1.0	R-2.2	R-3.3
Glazing	-	-	≤ 15% of conditioned floor area	R-1.5 ≤ 16% of conditioned floor area
Performance Alternative	A.L.F.	None	Calculation (Notional house)	Calculation (Notional house)

Table 1.3: Difference in prescriptive standards — a comparison of countries

In the United Kingdom a calculation procedure is used that has the option of calculating the rate of heat loss or the annual energy use in a proposed house and comparing this with a notional house. This also gives the option of looking at other forms of energy use such as passive solar, offering wider opportunities.

The Californian performance-based code is very sophisticated and is geared towards energy efficiency. It is based on the annual energy budgets that are calculated by combining the water and space heating yearly budgets for the proposed and notional houses. Once again, the proposed house is compared to a notional one. It allows for deductions of energy if efficient equipment is going to be used in the house or if energy is supplied from a renewable source.

The BIA and EECA are currently (1995) reviewing both domestic and building energy efficiency code requirements.

1.5 Barriers to Energy Efficiency

Unfortunately, substantial barriers exist that slow the uptake of energy efficient measures in the domestic sector. These barriers are divided into two factors, buildings and people.

Buildings being designed now and those that will be designed in the future will utilise many of the new techniques and systems that can lead to maximised energy efficiency. However, with the present building inventory being replaced at a slow rate (around 18,000 houses per annum in a stock of 1.3 million) the majority of existing houses for many years to come will be those that were not originally designed with energy efficiency in mind. Thus the use of energy in existing domestic houses must become a matter of real concern as the nation heads towards a goal of energy efficiency. This means that the retrofit market needs to be targeted for energy efficiency.

It is also important that house owners and occupants become more aware of not only what they can do to make their house more energy efficient, but also how to use their houses more efficiently. There are several cost-free ways people can reduce the amount of energy they use by implementing behavioural changes.

Consumers need to have better access to appropriate information regarding particular technologies and appliances, and energy efficient appliances need to be more locally available. Architects, engineers, builders, designers and suppliers are often unaware of the potential for energy efficiency or are unaware of how to market this potential to consumers. Houses that are not owner occupied are another barrier to energy efficiency. Landlords are disinclined to invest as they rarely benefit from upgrading the dwelling and tenants are disinclined due to the long payback period.

These barriers are, cumulatively, very significant and account for the fact that a large proportion of the cost-effective energy efficient technology available has not yet been implemented by the residential sector.

1.6 Future Changes in Domestic Building Energy Use

Energy efficiency improvements over time are difficult to forecast because of the number of variables involved. It is difficult to predict energy consumption and how the efficient use of energy is going to change the amount of energy used in the domestic sector. This is partly due to the lack of information on how energy is used in New Zealand homes and the small amount of data that is available has many inherent assumptions. It is also difficult to predict how behavioural patterns will change as a result of people becoming more energy conscious.

Other factors that affect the forecast, even in the absence of government policy changes, are accelerated technological advancement, increases in real energy prices and the turnover rate of housing stock. The forecast assumes that these factors will continue to change in the future in a manner similar to the way they have changed in the recent past. All of these may contribute to the rate at which energy efficiency improves over time.

Energy efficiency improvements can have a significant effect on the mix of fuels. For example, in the electricity industry it is believed that new electro-technological developments will enhance the efficiency with which electricity can be used relative to other energy forms and boost the demand for electricity (ECNZ, 1994).

Despite all these variables, there have been forecasts on energy supply demand and energy efficiency in the year 2000 .

It is claimed (Ministry of Commerce, 1991) that if a new home was built with energy efficiency as a major objective, savings of approximately 60% of energy demand can be made without reducing the quality of service (Table 1.4). This report makes no assumptions about the rate of housing replacement and growth in housing numbers and, therefore, no prediction on energy use in the year 2000 is made. An intelligent guess is around 18,000 new houses per year, or 108,000 in six years. Current stock is 1.3 million houses, so less than 10% could be affected.

The main work done on the potential for energy conservation in New Zealand houses is by Wright and Baines, written in 1986 but based on 1972-73 statistics. They used the 1985 Ministry of Energy Econometric Forecast as a base and produced a forecast with the intention of answering “What might the energy demand in the domestic sector be in 15 years hence if an aggressive programme of energy conservation were to be adopted?”. The Wright and Baines forecast concluded that 1.4 PJ/yr less electricity would be required if energy conservation measures were adopted. This saving amounts to only 3.3% of the household electricity demand forecast for the end of the study period.

Many estimations and assumptions were used to reach their conclusion. These included an increase in houses of 20.4%, all houses built after 1985 would be insulated in accordance with the 1977 standard (NZS 4218P), and an estimation of the increase in appliances was made. Their forecast does not include upgrading of the hot water cylinders to the NZS 4602:1988 level. The Wright and Baines estimates, while based on the notion of an aggressive programme, are fairly discouraging. A recent study of the potential for energy efficiency in the household sector is a bit more encouraging (Harris, 1993). This study concluded that:

> *In households, simple measures related to water heating, lighting, space heating and refrigerators could save at least 14% of household energy use over time.*

Measure	% of total household energy demand	Achievable energy savings as a % of column 1	Total energy savings as a % of total household use
Water heating	40%	70%	28%
Space Heating	20%	70%	14%
Cooking	10%	50%	5%
Lighting	10%	80%	8%
Refrigeration	10%	40%	4%
Other	10%	20%	2%
Total			61%

Table 1.4: New homes - achievable savings (c.f. existing practice) (Ministry of Commerce, 1991)

The study report then went on to describe a range of public policy measures to achieve this reduction. In the absence of a significant change in the uptake of energy efficiency household energy demand will continue to grow. The Ministry of Commerce has predicted household consumer energy demand out to the year 2000 using an econometric model (Ministry of Commerce, 1994). The model has a degree of energy efficiency improvement built in, but not as much as is technically possible. For the residential sector, the first stage of modelling involved the total residential energy demand, and the second stage involved breaking the aggregate down into the demand for separate fuels.

The model is chiefly dependent on energy prices, income (indicated by GDP per capita) and temperature (indicated by degree days). Assumptions were made for the following factors: the future price of the different fuel types, New Zealand's GDP and population, and improvements in energy efficiency. No social or environmental costs were taken into account.

The result of this forecast is illustrated in Figure 1.10. Total residential energy demand is forecast to grow from its 1990 level of about 41 PJ to around 47 PJ in the year 2000. The consumption of electricity and gas is expected to rise and the consumption of both oil and coal steadily decline.

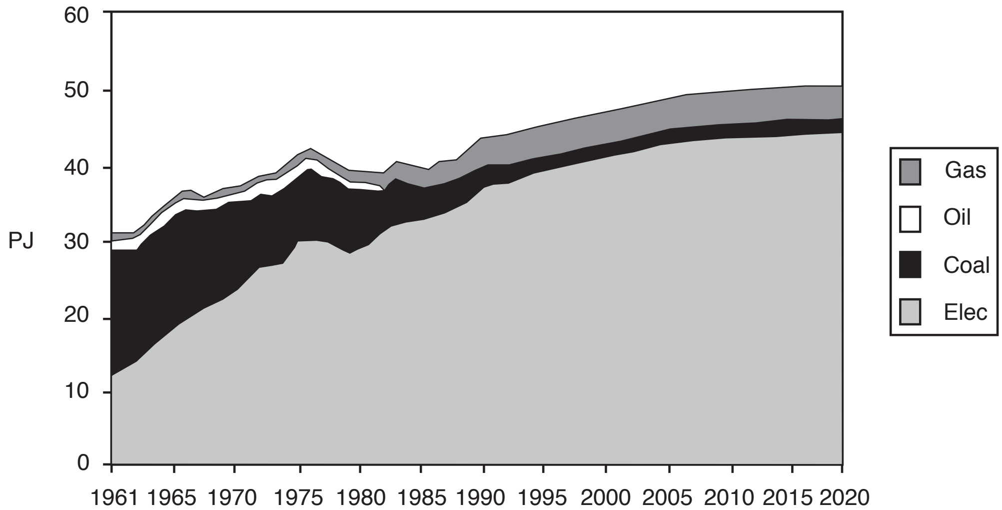


Figure 1.10: Residential sector consumer energy — fuel contributions (PJ) (Ministry of Commerce, 1992)

1.7 Summary

The domestic sector consumes mainly electricity (71%) for its energy use, although wood (14%), coal (7%) and gas (7%) are also used. The main uses of this energy are for space heating and hot water heating, which together account for 75% of the total energy use in a house. The forecast shows that the electricity fuel share for the residential sector rises slowly through to the year 2000 and gas increases at the same time as coal decreases (Figure 1.11).

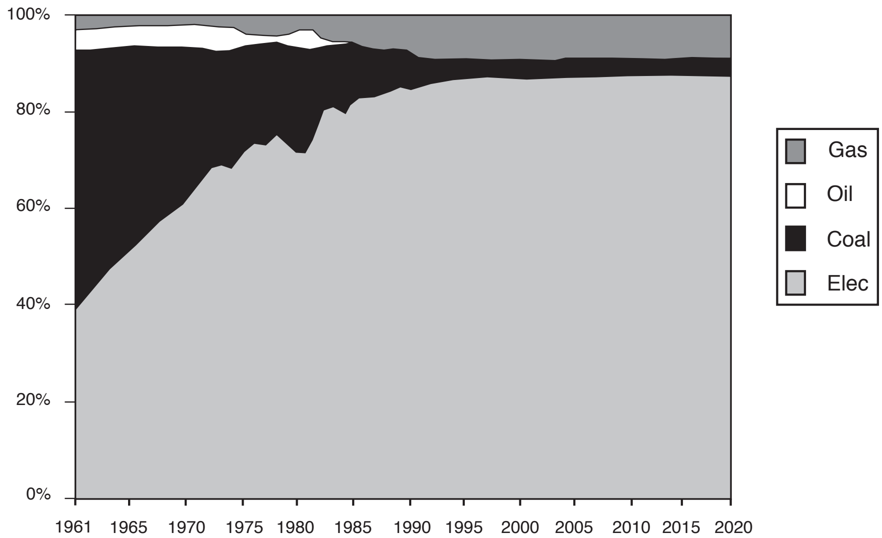


Figure 1.11: Residential sector consumer energy — fuel share percentages (Ministry of Commerce, 1992)

There are three major factors that affect the energy efficiency of a house: the design, the appliances within the house, and how the homeowner uses the house. For New Zealand homes to become more energy efficient, all three factors will have to be considered at a national level.

New Zealand's insulation standard is lower than most overseas standards, and only approximately 30% of the current housing stock reaches that level. To make an impact on energy efficiency, the older housing stock that doesn't reach the current standard will have to be upgraded. For new housing, orientation towards the sun, position of glazing and materials used should be considered at the design stage.

Appliances are becoming more energy efficient, but the rate of replacement will control how quickly they have an effect on domestic energy use nationally, as will the number of appliances in use around the house. If New Zealanders continue to increase the number of appliances, any savings gained from more efficient appliances will be offset.

The amount of energy required for space heating is largely dependent on the design, material and insulation of a house. However, some heaters are more efficient than others (e.g. heat pumps are much more efficient than open fires).

Hot water accounts for, on average, 38% of a household's energy demand. Reductions in this can be from decreasing the amount of hot water used by changing behavioural habits and using more efficient appliances. The best insulated cylinder (NZS 4602: 1988 Type A) is 37% more efficient than the previous standard (NZS4602:1976).

The New Zealand Building Code does not require the use of an energy efficient hot water cylinder, nor is there any requirement for an energy efficiency level to be met for any general appliance. The code does state a minimum acceptable level of thermal insulation; however, the standard associated with this has not been upgraded since 1977.

Very little is known about how much a change in behavioural habits will decrease the amount of energy used in a household. Better access to information about energy efficiency for all New Zealanders is required before behavioural changes can be made as people are often unaware of what can be done in their home to save energy.

References

ACC and Plunket (1990). "Hot Water Burns Like Fire", *Standards Magazine*, Vol. 40, No 10, Wellington.

Bassett M R, R C Bishop and I S van der Werff (1993). *ALF Manual— An aid to thermal design of buildings*, BRANZ.

BIA (1992). *The New Zealand Building Code.*, Building Industry Authority.

BRANZ (1988). *Solarhart 300K Solarhart 180K Solar Hot Water Systems*, Appraisal Certificate No 166.

BRANZ (1992). *Thermal Insulation of Houses*, Bulletin No 292.

Breuer, D (1986). "Value of insulation and thermal mass in new house heating", *New Zealand Engineering*, August 1986.

Consumers Institute (1992). "Energy saving lightbulbs: a word of caution", *Consumer* No. 307, August 1992.

Consumers Institute (1992). "Solar systems — is solar water heating a realistic option?", *Consumer* No. 309, October 1992.

Consumers Institute (1993). "How to make your own power cuts", *Consumer* No. 314, April 1993.

Consumers Institute, (1993). *In Search of Excellence — What 'quality symbols' really mean,* Consumer No 318, August 1993.

Department of Statistics (1991). *Census of Population and Dwellings 1991*.

ECNZ (1994). *Electricity Supply and Demand in New Zealand: a Discussion Paper prepared by the Electricity Corporation of New Zealand*, Electricity Corporation of New Zealand.

Electrical Development Association, *Watermark*, Wellington.

Harris G, et. al. (1993). *Promoting the Market for Energy Efficiency*, report to the Officials Committee on Energy Policy, Wellington.

Isaacs I P and H A Trethowen (1985). *A Survey of House Insulation*, BRANZ Research Report R46.

Isaacs I P, (1993). *Thermal Efficiency in New Zealand Buildings: a Historic Overview*, Centre for Building Performance Research, Victoria University of Wellington.

Isaacs I P, M Greenough and G Crust (1994). "Energy efficiency and overseas building codes", *Transactions IPENZ,* General Engineering Section, Vol. 21, July 1994, pp. 2-5.

Massey University (1992). *End Use Database for the New Zealand Economy*.

Ministry of Commerce, (1994). *Energy Supply and Demand Scenarios to 2020*, Wellington, 1994.

Ministry of Commerce (1991). *Energy Management and the Greenhouse Effect*, Wellington, January 1991.

New Zealand Meteorological Service, (1983). *Summaries of Climatological Observations to 1980*, N.Z. Met. S. Misc. Pub. 177.

NZS 4218P:1977. *Minimum Thermal Insulation Requirements for Residential Buildings*, Standards Association of New Zealand.

NZS 4602:1988. *Low Pressure Copper Thermal Storage Electric Water Heaters*, Standards Association of New Zealand.

Page, I (1994). Economist, BRANZ, *Pers. Comm.*

van der Werff, I (1993). *Pers. Comm.*

Wright J and J Baines (1986). *Supply Curves of Conserved Energy, The Potential of Conservation in New Zealand Houses*.

Chapter 2
Solar House Design

2.1 Introduction

New Zealand has three to four hours of bright sunlight per day on average in the north, and in sunnier South Island regions (e.g. Blenheim), and two to three hours further south. Even when it is cloudy, solar energy is still available. On average, the sun has the potential to supply around 3 to 4 kWh of energy per square metre per day. The amount of energy from sunlight falling on the roof of a typical house over a year adds up to over ten times the average annual energy demand of the home. The problem is how to convert the sunlight into useful energy. Four types of useful energy can be derived from sunlight.

Photovoltaic technologies can be used to convert sunlight into household electricity. This is presently only economic in remote locations where the price of electricity from alternative sources is expensive. The development of efficient photovoltaic cells is proceeding and some companies (e.g. Pacific Energy in NSW) believe that within ten years, household photovoltaic power will be competitive with grid electricity.

Sunlight can be used to heat water, and this application is covered in Chapter 12. Daylighting is provided by sunlight entering windows. Skylights of various forms are available to allow sunlight into rooms with few or no exterior windows. Special technologies are being developed to help get sunlight further into the interiors of office buildings and these may be adapted for domestic use.

This chapter covers solar homes, houses designed so that the sun can provide a significant share of the space heating required. Nearly all homes receive some space heating from the sun. The issue explored here is how to improve the solar gain and its usefulness. Many very good solar design references are available and the material that follows is only an overview of the subject.

The key factors involved in solar space heating are:

- house location and design;
- system configuration;
- collector types;
- window design; and
- thermal mass.

These factors are elaborated below. House location and design will be dealt with last as the points made will be more evident after the material on solar system configuration. Whether or not a house is specifically designed for enhanced solar space heating, the benefits of thermal mass have generally been overlooked in New Zealand. For this reason, Chapter 3 is devoted to the subject of thermal mass in the New Zealand context. The role of thermal mass in solar design is therefore only briefly referred to in this chapter; Chapter 3 should be read in conjunction with this chapter.

In general, it is not practical to rely only on solar heating to provide a comfortable home. Some form of backup heat will be necessary for rooms with inadequate sun access, or to provide heat early in the morning or during prolonged cloudy or cold periods. Consequently, solar house design should be seen in the context of overall energy efficient practice. It is not a substitute for a well insulated home, draughtproof, yet properly ventilated.

The cost of building in certain types of solar heating features, such as an insulated concrete floor slab, may not add much to the cost of a new home. The cost of other solar technology and retrofits will depend on the skills and access to materials enjoyed by the homeowner. There are many manuals on solar design that provide do-it-yourself opportunities.

The benefits of good solar design in New Zealand will depend mainly on geographic location, the collector type used, and the area and standard of glazing or window insulation. The savings in the use of heaters can vary from around 20% in Auckland for the least effective collector system to around 80% with the best system. In Invercargill, the range is thought to be from 20% to around 50%. Further information on the benefits of solar design in the New Zealand context is provided below.

Passive solar design does not require radical departure from conventional construction methods. Careful attention to detail is required, however, particularly relating to insulation, moisture control in wall and roof cavities, and allowance for expansion, especially in walls used for thermal storage. The construction issues for passive solar houses in New Zealand are well covered in a 1990 Ministry of Commerce publication (Donn, 1990).

2.2 Solar Systems

There are various ways to categorise solar space heating systems. Systems can be passive or active. Active systems use pumps or fans to convey the heat to storage and from storage to the house spaces. Passive systems rely on conduction, convection and radiation. In reality, most systems are a mixture of active and passive elements (e.g. the use of a ceiling fan in an otherwise passive design). Various types of heat transport mediums are used. The systems described below use warm air, the most common medium. Hot water can be used to collect, store and transport energy and warm living spaces. Systems using water are similar to solar water heating units except that the end use of the water is to provide space heating via radiators. Refer to Chapter 12 for information on solar water heating.

The four types of systems described below are differentiated on the basis on their collector/storage elements:

- simple direct gain;
- indirect gain;
- greenhouse units; and
- separate collector/storage.

There are means to enhance the solar collection potential on any of the above systems and these are discussed following a description of each type of system.

Simple Direct Gain

This system requires the least change from conventional house design. The essential elements are windows to let sunlight fall on a thermal mass, which stores the heat and releases it when room temperatures fall (Figure 2.1). The thermal mass should satisfy three requirements:

- it should be able to efficiently absorb heat through its surface;
- it should have an adequate storage capacity per unit mass or volume; and
- it should be placed so that minimal heat is lost to outside air.

The collection and storage element is often an insulated concrete floor, but other elements with thermal inertia could be used, such as reversed exterior brick walls (insulation and cladding on the outside), double layers of gib board, internal masonry walls, a feature fireplace, a spiral brick staircase or some other architectural feature or structural element. Water-filled drums or tanks are also used to provide thermal mass. Some phase change materials have very good energy storage per unit volume and could also be placed in containers. To be effective, direct gain systems need an adequate window area and duration of incident sunlight on the thermal mass. Window size is discussed later, but is mentioned now because the main way to manage a direct gain system, once it is built, is by either shading windows or shielding the thermal mass from the sun.

Conversely, inadvertent shielding can detract from performance. Many floor coverings, carpet in particular, will reduce the effectiveness of a thermal mass floor. Dark tiles, slate and, to a lesser extent, cork would be suitable coverings.

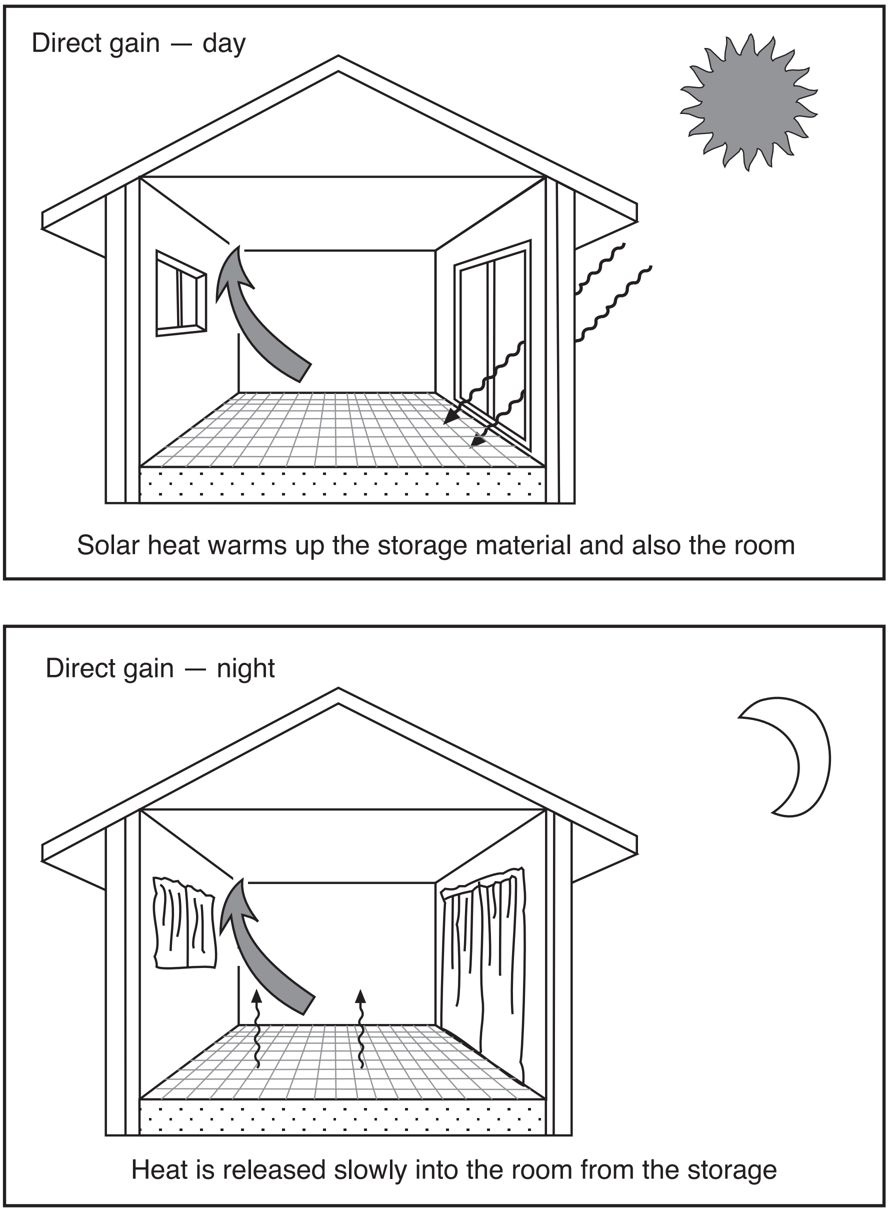


Figure 2.1: Direct solar gain (Ministry of Energy, 1983)

Indirect Gain Systems

An indirect gain system provides space heating without sunlight penetrating the living space. Like the simple gain system, the solar collector is integral with the storage. Indirect systems usually take the form of a solid external wall covered with glazing. Figure 2.2 shows a typical configuration that is often referred to as a Trombe wall. The glazing serves two functions. It protects the wall from convective heat losses due to wind, and it intercepts and re-radiates back some of the infrared energy lost from the wall (the wall will tend to radiate heat equally in both directions). The effectiveness of the wall can be improved substantially (20% or more) if insulation is placed between the wall and the glazing at night. For example, a curtain padded with polyester insulation could be drawn across the space. The inside of the wall can be plastered, painted etc., but should not be insulated (or have an air gap between the wall and any lining). The outside of the wall should be painted a dark colour if the construction material is naturally a light colour.

A disadvantage of an indirect gain system is that it can take several hours into the day before any significant heat moves into the room behind the wall. This can be dealt with in several ways. Figure 2.2 shows the option of drawing warm air from in front of the wall to provide space heating during the day. The air flow needs to be adjusted so that it does not draw away too much heat and compromise the heat storage. As warm air enters the room from the top of the wall, a low-speed ceiling fan would be useful to provide an even temperature throughout the living area. Alternatively, in a multi-storey home, the wall could vent at the floor level of a room above. Another option is to place some windows in a Trombe wall to provide an element of direct gain to accelerate warming of the room early in the day.

Suitable materials for the wall are concrete, concrete block, bricks and other masonry. Water is also a suitable medium. For example, a wall made out of dark bottles cemented together would allow some light through while providing good heat storage. It may be necessary to place sterilised water in the bottles or to add a chemical, such as bleach, to avoid algal growths.

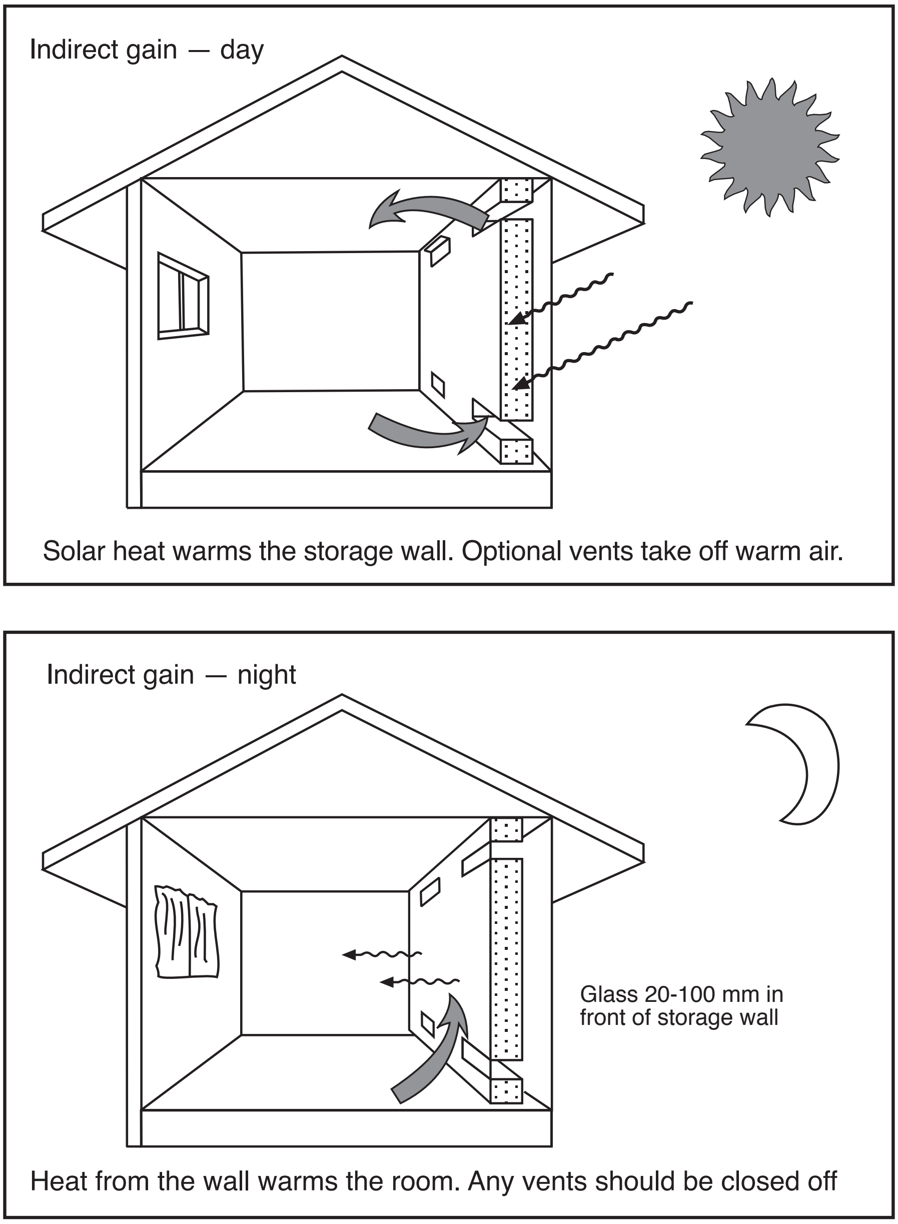
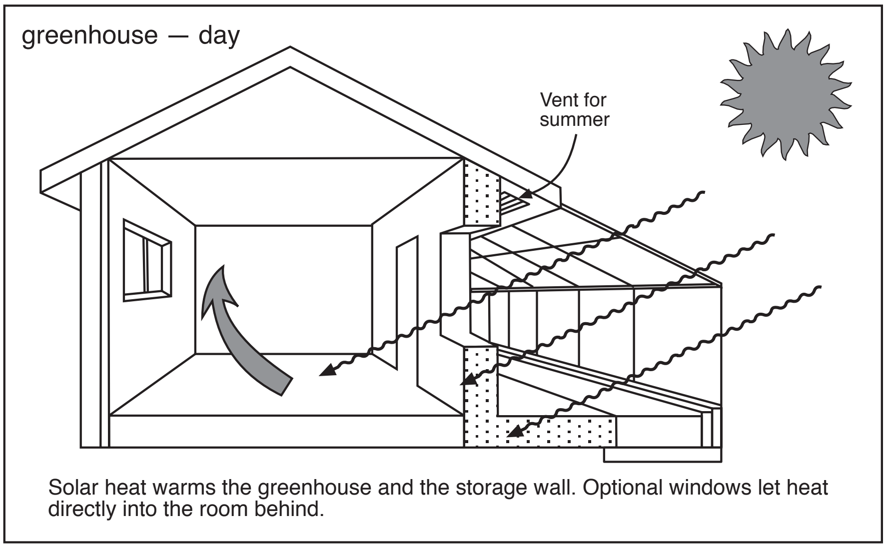


Figure 2.2: Indirect gain system (Ministry of Energy, 1983)

Greenhouse Units

A greenhouse, or sunspace, attached to the northern side of a house may be the easiest retrofit option for an existing house. To gain best advantage of the greenhouse, there should be thermal mass that adjoins the living area. A greenhouse, such as shown in Figure 2.3, can be made to be a hybrid between a direct and indirect gain system. During the day the greenhouse can be used as a warm living room with direct gain. Windows can be used to provide direct gain to the interior room as well. At night, the interior living space can be heated by the greenhouse wall in a similar manner to a Trombe wall. While not shown in Figure 2.3, warm air from the greenhouse can also be vented into the house during the day.



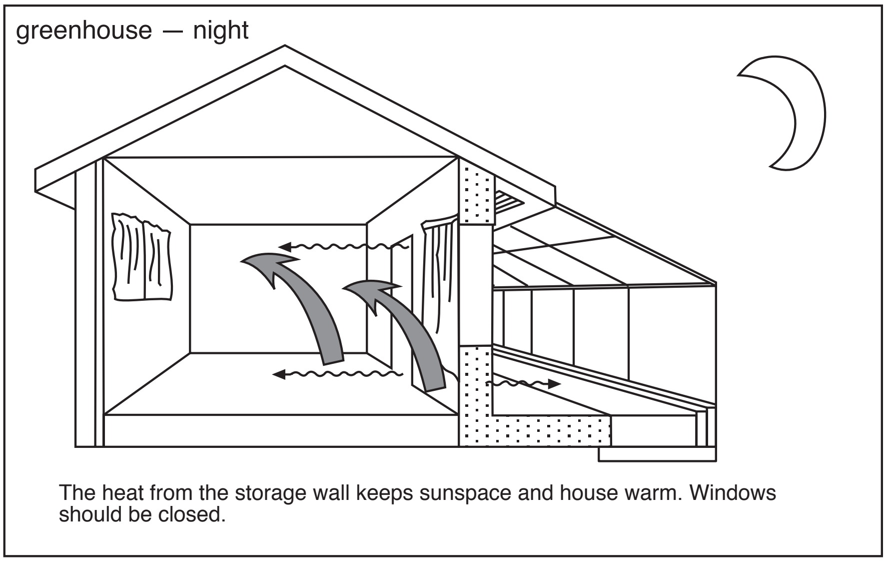


Figure 2.3: Greenhouse unit (Ministry of Energy, 1983)

Water in drums placed in the greenhouse can increase its thermal mass. This will not materially help to heat the house, but it could allow the greenhouse to remain warm longer into the evening which might be advantageous (to extend the use of the greenhouse or to help plant growth). Insulating a glasshouse at night is difficult due to the large glazing area. Blinds could be used to prevent direct radiation to the dark night sky. In terms of interior heating the best effect would come from insulating the back wall with a night-time curtain in the same manner as suggested for a Trombe wall.

Greenhouses (and Trombe walls) are prone to overheating in summer, but can also cause problems in spring and autumn. A number of strategies are available to deal with this. Firstly, there should be adequate facilities for venting hot air inside the glazed space to the outside. Secondly, shading (e.g. shade cloth) can be installed as summer progresses and adjusted to suit sunlight levels. While a little unsightly, glazed areas can be painted at the start of summer with compounds (e.g. whitewash) that gradually wash off so that the glass is clear by autumn. Trombe walls and the vertical back wall of a greenhouse can be shaded in summer by an eaves overhang.

Separate Collector/Storage

Hot air collectors can be constructed from sheetmetal and glass. Air rises, or is forced between dark sheet metal and the glazing, and gains solar energy. The air then moves into living spaces by convection or aided by a small fan. Alternatively, the air is passed through, and gives up its heat to a storage unit. Heat is removed from the storage unit by convection or forced airflow later in the day.

Lightweight collectors which resemble solar panels for water heaters can be retrofitted to existing homes. Instead of being on the roof, they are usually placed at an angle against northerly aspect walls. They can be used to overcome shortcomings in building orientation since the collector and living spaces do not have to be adjacent (insulated ducting would be needed). If no storage unit is used, then the system relies on the inherent thermal mass of the house: concrete floors, gib board linings etc. If there is insufficient thermal mass, considerable temperature swings will occur. Temperatures will build up early in the day and fall quickly once the sun is lost.

Reasonably economical thermal storage can be provided by constructing an insulated box and filling this with small, rounded rocks to provide a large surface area for heat exchange (but not too much resistance to airflow). A system of vent controls allows heat to be stored in the box during the day and released at night. The ideal location for the rock box would be under the main living area so that convection can be used to recover the heat.

Separate collector and storage systems are suited to steeper sites where masonry walls and concrete floors are less desirable structural elements. Steep terrain often favours light timber-framed construction with suspended wooden floors or pole house design. Multilevel homes, in particular, are well suited to separate collectors as convection can be used to move hot air around, and underfloor spaces may be available for rock storage.

Enhanced Collection

The solar collecting potential of any of the above systems can be enhanced in a variety of ways. Reflective surfaces can be used to overcome limitations of the basic collector design, such as lack of north facing area. Placing a shallow pond adjacent to a Trombe wall, for example, can dramatically increase its performance by reflecting sunlight onto the wall. A white painted surface inclined at a suitable angle and adjacent to a sheetmetal and glass collector could add another 50% or more to the energy gain of the system. The solar gain (and interior lighting) through east aspect windows could be significantly enhanced by painting an adjacent fence or garage white. Care must be taken to avoid glare problems with reflective surfaces. Painted surfaces must be kept clean to be effective.

2.3 Solar Collector Design

This section covers solar window area, inclination, orientation and associated shading issues. The relative benefits of windows, greenhouses and Trombe walls are discussed. The section then touches on the subject of thermal mass. Passive solar design guidelines for New Zealand have been prepared and published by the Ministry of Commerce (Pacific Energy Design Ltd, 1985; Donn, 1990).

Solar Window Area

The ratio of glazed area to the floor area of the living space to be heated is a critical parameter. Too little area of glazing and the space will remain cold, even on a sunny winter's day. Too much glass and the room will overheat. Glazing areas also need to be balanced with an adequate level of heat storage.

To develop some New Zealand passive solar design guidelines, the effect of changing a range of parameters for a standard house was simulated. The Building Industry Advisory Council Standard House was the starting point. This house is approximately 100 square metres in area with floor plan and window size and placement typical of New Zealand homes. Significant energy savings are possible just by rearranging the floor plan so that the living rooms have more glass area and face the sun. These changes led to a base solar house that reduced purchased space heating energy by 70% in Auckland, 45% in Wellington and 25% in Christchurch and Invercargill. This base house was then used to test the effect of changing window sizes, adding sunspaces, etc.

The simulation studies showed that increasing the area of north facing glass in the base solar house beyond 10 m^2 to 13 m^2 in Auckland and Wellington makes no difference to the annual heating energy requirement. It only increases the amount of time that overheating occurs. In Christchurch and Invercargill, increasing the area of north facing glass beyond about 10 m^2 increases energy demand, albeit only slightly, as well as increasing the occurrence of overheating.

Window Orientation

In the southern hemisphere, vertical windows facing up to 30 degrees northwest or northeast may collect as much winter's sun as those facing due north.

In summer, northwest windows will be letting in light during the hottest part of the day and overheating could occur. The lower sun angle in the afternoon can make control by shading difficult. Deep pergolas with deciduous creeper or deciduous trees in front of northwesterly solar windows can reduce summer heating.

The standard solar home referred to above had 4.6 m^2 of west facing windows. Doubling this area in Auckland actually increased the annual heating energy use. The extra solar gain could not be used and the extra ventilation and window heat loss meant more heating was needed in the evening. In the colder climates, the gain and losses tended to cancel each other, and there was little net effect. Halving the west window area reduced the annual heating load in Auckland, Christchurch and Invercargill.

Northeastern windows could cause overheating if they are excessively large. Simulation studies, however, showed that doubling the glass area of the standard solar house to 6.8 m^2 had no major effect on the annual heating energy use or the hours of overheating. East windows appear to be less of a problem than northwest windows because the heating occurs during a cooler part of the day. In fact, rapid temperature buildup may be desirable to deal with cold mornings.

Window Inclination and Control

Roof glazing or skylights allow sunlight to penetrate the interior of a house and are a common retrofit. Skylights are less likely to be shaded by trees and neighbouring buildings. They will collect far more sunlight in summer than in winter and could lead to overheating unless provision is made for adjustable shades. Clerestory windows also allow light to penetrate a home, but the vertical glazing automatically "reduces" the amount of summer sunlight. Furthermore, they are easier to fit with blinds and shades than skylights. They may be a better option, especially in a new house.

Windows could be designed, made larger for example, to trade off potential summer problems for better winter performance. While vertical glazing automatically reduces the interior area exposed to sunlight in summer, overheating may still be a problem. This can be dealt with by using an adequate eaves overhang to shade the glazing from the summer sun. Adjustable exterior shades can be drawn down from the eaves to provide fine control.

Greenhouse/Sunspace

A sunspace will usually have sloping glass and may overheat, but this need not be a problem. A sunspace is an optional place for activities and can be avoided when it is too hot. The excess heat can be stored in the thermal mass of the sunspace and used to warm the house later. Several variables have an effect on sunspace performance:

- the length of sunspace along the north wall;
- the area of glass between the sunspace and the house interior;
- thermal mass in the interior wall; and
- insulation of the thermal space.

The main living areas of the standard solar house have large windows facing north. Covering the exterior living area walls and windows with a sunspace is the starting point. Given this start, it is generally not worth increasing the extent of the sunspace beyond more than 50% of the north wall length, without adding thermal mass to the interior wall. If the interior wall window area is increased by about 25%, then a 25% solar space (i.e length equal to one-quarter of north wall length) can provide the same performance as a 50% solar space.

A sunspace with a conventional insulated roof and side walls, and only a glass front, will perform nearly as well as an all-glass unit. Using double glazing is beneficial in both cases, and adding thermal mass to the interior wall will enhance thermal performance. Table 2.1 shows the annual energy use in a standard solar home and one with a well-designed sunspace for different home heating regimes (S an d UH). On a proportional basis, a sunspace in Auckland will have the greatest effect (standard heating regime). On an absolute energy basis, the benefits are greater in the South Island, where savings of 2 to 3 GJ per year can be achieved. The benefits of a sunspace are even greater if the objective is to provide 24-hour-a-day heating.

Heating/House	Auckland	New Plymouth	Wellington	Nelson	Christchurch	Invercargill
S/Standard	0.3	1.3	1.5	3.0	6.6	8.7
S/Sunspace	0.1	0.8	0.7	1.9	4.3	5.5
UH/Standard	5.8	11.0	11.3	13.7	19.9	25.8
UH/Sunspace	4.5	8.8	8.7	11.0	16.5	21.2

Heating Options: S (Standard) 15˚C/18˚C Bedrooms/Living Areas 7am — 11pm
UH (Uniform High) 15˚C/22˚C Bedrooms/Living Areas 24 hours

Table 2.1: Annual heating demand (GJ) — standard solar home vs. one with sunspace

Thermal Storage (Trombe) Walls

Ideally, Trombe walls should extend the full length of the north aspect of a house to get the best benefit. Interestingly, short Trombe walls in Wellington (one third of the north wall) are slightly counterproductive, while they are beneficial in other centres. A 50% Trombe wall will decrease the heating energy use by 60% in Auckland, 25% in Wellington and 17% in Christchurch and Invercargill. Table 2.2 shows the potential benefits of a well designed 100% Trombe wall. The result of presenting figures to one decimal place suggests a 100% reduction for Auckland (standard heating regime), but the actual simulation outcome is 80%.

Heating/House	Auckland	New Plymouth	Wellington	Nelson	Christchurch	Invercargill
S/Standard	0.3	1.3	1.5	3.0	6.6	8.7
S/Trombe	0.0	0.6	0.8	1.6	4.8	6.2
U/Standard	2.3	6.0	6.2	8.8	14.0	19.0
U/Trombe	0.2	1.5	2.0	3.2	8.2	10.5
U/Sunspace	1.4	4.2	4.2	6.6	11.0	15.0

Heating Options: S (Standard) 15˚C/18˚C Bedrooms/Living Areas 7am — 11pm
U (Uniform) 15˚C/20˚C Bedrooms/Living Areas 24 hours

Table 2.2: Annual heating demand (GJ) — standard solar home vs. one with Trombe wall

Trombe walls are very good for uniform 24-hour heating. Heating to achieve this level of comfort can be reduced by 90% in Auckland with a Trombe wall. United States experience suggests a maximum room depth of 5 to 6 metres for effective radiant heating from a Trombe wall. Elongating the east-west axis of a house is a useful strategy. Stacking spaces to achieve a two storey wall is also helpful from an energy perspective, but is an expensive option in seismically active areas (this issue is addressed in the next chapter).

For the standard home heating regime, well designed Trombe walls are more effective than sunspaces in the North Island and the top end of the South Island. Trombe walls are a better option in all regions if uniform comfort levels are desired. This is well illustrated by comparing the last row of Table 2.2, which shows the performance of a sunspace with a uniform temperature regime, with the second last row showing the performance for a Trombe wall.

Thermal Mass and Other Options

Chapter 3 considers the practicalities of installing thermal mass in a home. This section discusses the issues of size and the benefits of thermal mass. Generally, the thermal mass coverage should be roughly equivalent to the area swept by the sunlight passing through the solar glazing. The minimum thickness of masonry units and concrete floors is usually set by structural requirements. Having an insulated concrete floor greater in extent than the sun-swept area will not compromise the solar performance. In fact, it could help to dampen out temperature swings from the movement of solar heated air, the use of internal heaters, etc. The same can be said of external masonry walls, with some qualifications.

There is no point in carrying glazing over part of an external wall that is shaded from the sun or only receives the sun for a short time. This part of the wall could still be masonry and connected to the Trombe wall, but it should be insulated. If it is intended that the wall section play a thermal mass role, then it should be insulated on the outside. Otherwise, it should be insulated on the inside. A case can be made for a short length of the wall (perhaps half a metre) to have insulation on the outside as well as the inside to minimise heat migration along the wall and its subsequent loss to the outside air.

The effect of additional insulation, thermal mass and double glazing has been examined and the results are shown in Table 2.3 (Breuer, 1988). The base case is a timber-framed house with a timber floor and single glazing. The solar system is the coincidental direct solar gain that most homes enjoy. In other words, the house has average window sizes and orientations.

If the home is weatherstripped and insulated beyond NZS 4218P, this will add over $800 to the construction cost. The benefits are less loss of solar gain and heat from interior sources (e.g. electric) and these will vary according to the climatic zone. Zone 1 is Auckland, Zone 2 Wellington, Zone 3 Christchurch and Zone 4 Southland. In Auckland, the cost of saved energy over ten years (ignoring the cost of borrowing) is 14c/kWh, an unattractive investment. In Southland, the cost of saved energy is around 4 c/kWh, a good investment.

Table 2.3 shows two further options additional to weatherstripping and extra insulation. The first is to build with a concrete slab-on-ground and use single glazing. The second is to use a concrete slab and double glazing. On flat sites, the net additional cost of a concrete slab is negative; it saves money. The slab reduces energy demand, but the effect is marginal in Southland. Double glazing adds to costs. The benefits of double glazing are greatest in Christchurch and Southland.

House Type (glazing/structure/slope)	Zone 1		Zone 2		Zone 3		Zone 4	
	$ cost	kW/h save	$ cost	kW/h save	$ cost	kW/h save	$ cost	kW/h save
Single glaze/timber	862	530	862	1190	862	1570	862	2100
Single glaze/concrete/0%	+2221	910	-2221	1680	-2221	2170	-2221	2230
Single glaze/concrete/6%	-937	910	-937	1680	-937	2170	-937	2230
Single glaze/concrete/12%	347	910	347	1680	347	2170	347	2230
Single glaze/concrete/24%	2920	910	2920	1680	2920	2170	2920	2230
Double glaze/timber	2281	690	2281	1510	1966	2060	2550	2700
Double glaze/concrete/0%	-802	990	-802	1990	-1116	2720	-533	3330
Double glaze/concrete/6%	487	990	487	1990	166	2720	749	3330
Double glaze/concrete/12%	1777	990	1777	1990	1449	2720	2032	3330
Double glaze/concrete/24%	4339	990	4339	1990	4919	2720	4602	3330

Table 2.3: Estimates of the cost/benefits of enhanced solar gain

This information indicates that in the North Island installing a concrete slab-on-ground floor is a good energy strategy on slopes up to 12% (it may also reduce construction costs). In Auckland, the benefits of double glazing may be marginal. Double glazing becomes more attractive in the lower half of the North Island (and possibly the central volcanic plateau). Setting out to optimise a house for solar gain in the North Island is likely to be very worthwhile.

In much of the South Island a concrete slab will save construction costs but will probably not make a big difference to energy conservation (unless additional efforts are made to enhance solar gain). In the colder zones, most of the initial benefit comes from extra insulation beyond that for NZ4218P. If a South Island home has a concrete slab, then it is worthwhile having double glazing. Overall, solar homes are worthwhile in the South Island, providing double glazing is installed. A home package of double glazing, extra insulation and a concrete slab on a slope of up to 12% in the South Island yields saved energy at 6 c/kWh (undiscounted) over 10 years.

Simulation studies on the standard solar house emphasise the benefits of a concrete floor. Increasing the floor thickness beyond 100 mm has little effect. Introducing a thermal wall between the living and bedroom areas significantly reduces energy use. Increasing the thickness of this wall beyond 200 mm provides little extra benefit. As for a concrete floor, the advantages of a masonry interior wall are much greater in the North Island than the South Island. The amount of sun available in the south is rarely enough to threaten overheating and therefore make extra heat sinks beneficial.

2.4 House Location and Design

A large number of considerations go into house design. This section describes design features that make the best use of the sun, but this goal may need to be compromised to take advantage of views or because of site limitations, etc. With clever design, however, solar heating and a wide range of other objectives can often be satisfied. For example, the use of a separate collector and storage may overcome site orientation limitations.

To take advantage of solar heating potential, a home should be aligned so that the main living areas face north (true north rather than magnetic north). An effective solar design is possible with the main elevation 20 degrees or so either side of north. To conserve energy, the house should be a compact shape, although to obtain good sun penetration a rectangular shape with the east-west width slightly greater than the north-south depth is best. Double storey construction can provide a compact shape and enables solar heat to be convected to the upper levels. The use of an airlock porch main entrance can be helpful. Too many projecting bays, however, increase the surface area to volume ratio and, hence, heat loss potential of a building. Placing an earth berm over the southern side of the building or setting the building into a slope can be a useful strategy, but careful attention to waterproofing is required.

Placing the house close to the southern boundary will allow some control to be exercised over potential shading (e.g. from trees) from the north and will allow space for reflective elements such as shallow pools. The north elevation should receive the sun from at least 9.30 a.m. to 3.30 p.m. in winter. Shelter from prevailing winds, especially in winter, is useful. Hillocks, other buildings (e.g. a garage) or trees may be able to provide shelter without blocking the sun. Deciduous trees can be used to prevent overheating in summer. Care must be taken to ensure that the southern side of the home does not become too damp, prone to moss growth etc., due to shading and the presence of trees reducing airflow. Home security is another consideration in the placement of trees.

Solar heating lends itself to open plan layout. Generally, living rooms, dining rooms and, to a lesser extent, kitchens should be in the warmest part of the house. They should be located on the northern side of the house, adjacent to the solar heating units. Bedrooms, bathrooms and laundries can be placed on the cooler side of the house. Natural light for these rooms can be problematic. At all times of the year, south windows lose more heat than they collect and the loss in winter can be significant.

The use of north facing clerestory windows for south side rooms allows light penetration and a net heat gain (double glazed south of Auckland). Proprietary dome-shaped skylights with light tubes let in light without the risk of overheating. They also lose little heat. It is a useful principle to keep surfaces not involved in heat absorption as light in colour as possible. These surfaces then reflect light to those surfaces intended to act as heat stores and increase daylighting. Generally, all interior surfaces not struck by the sun or intended for heat storage should also be light in weight and insulated if part of the building envelope. This will reduce the amount of energy needed to warm these surfaces.

Inclined ceilings can be used to facilitate passive air movement to other living areas or to recirculation points. Slow speed fans are very useful to ensure that the air is well mixed or to recycle warm air from high points where stratification is likely (a 60 to 80 W fan can effectively provide 1 kW of heating by reducing thermal stratification). One of the potential advantages of solar heating is the all-round comfort that is possible by not having highly concentrated heat sources. Detail design of air movement, vents, fans, etc. should realise this potential.

References

Breuer, D R (1988). *Technical-Economic Assessment and Market Potential for Reducing Energy in Residential Buildings*, New Zealand Energy and Research Committee Contract 3290 Final Report No. 172.

Donn, M R and I van der Werff (1990). *Design Guidelines: Passive Solar in New Zealand*, Energy and Resources Division Report RD8831, Ministry of Commerce, Wellington.

Donn, M R, I van der Werff and G Miller (1990). *Construction Issues: Passive Solar in New Zealand*, Energy and Resources Division Report RD8832, Ministry of Commerce, Wellington.

Ministry of Energy (1983). *How to Heat Your Home*, published by the Ministry of Energy and Asia Pacific Economic News, Wellington, 1983.

Pacific Energy Design Ltd. (1985). *Design for the Sun: Residential Design Guidelines for New Zealand* (Breuer, D R, ed.) (2 volumes), Ministry of Energy, Wellington.

Chapter 3
Importance of Thermal Mass

3.1 Introduction

This chapter covers the importance of thermal mass in homes, the practicalities of installing thermal mass and the temperature control issues that might need to be addressed with its use. Readers unfamiliar with the basic principles of solar house design will find that Chapter 2 provides essential background to this chapter.

Hour-by-hour variations in outdoor temperature, and in the solar intensity incident upon a building, mean that any building unable to dampen out fluctuations in external environmental conditions will, inevitably, experience daily swings in its internal temperature and, hence, in the comfort conditions experienced by the occupants. Expressed simply, the addition of significant quantities of high density material (for example, concrete or water) within the building envelope will reduce the extent of such temperature swings by acting as an energy flywheel, absorbing excesses of energy when internal temperatures are high and releasing absorbed energy back into the internal space when the space temperature falls.

While conceptually this is a simple, and perhaps obvious principle, the effective implementation of "thermal mass" requires an awareness of the interdependency it has with solar gains (generally via glazing), the insulative performance of the building envelope and the nature of the climatic variations to which the building is exposed. A lack of awareness of this interdependency can result in house designs that perform poorly from the points of view of both thermal comfort and space heating energy requirements.

For this reason alone, there is merit in the Australian GMI (Glazing-Mass-Insulation) scheme, which has been promoted for a number of years and which, by its very name, reinforces the fact that all three aspects must be considered in producing effective passive solar designs for houses. Throughout the world, in fact, the addressing of energy efficiency in building codes often incorporates all three aspects (e.g. in California), with trade-offs between the extent to which the design implements each aspect. In such codes, the effectiveness of the design is generally evaluated using designated modelling software. At present, the energy component of the New Zealand building code only *indirectly* includes the possible benefits of glazing and/or thermal mass by allowing the use of the ALF (Annual Loss Factor) procedure (Bassett, 1990), with its inherent treatment of glazing and mass, to demonstrate compliance with the code (refer, for example, to Section 1.4 of the Overview Chapter).

By and large, the New Zealand public is aware of the benefits of adding insulation to a house, with improved thermal comfort obtained for the same energy input or, perhaps, less energy input for the same level of thermal comfort. Just as obvious is the fact that properly located areas of glazing are an effective means of admitting significant quantities of solar energy into the building. The significance of thermal mass in achieving thermal comfort and/or reduced space heating energy input is much less widely appreciated, however, and this may in large part stem from the fact that typical and traditional New Zealand wooden-framed and wooden-floor house construction contains very low thermal mass.

Even modest attempts to properly incorporate appropriate thermal mass into a modern New Zealand home can produce significant energy benefits. A national study of 28 houses showed that, on average, "standard" houses with a concrete floor slab saved 40% of space heating energy compared with equivalent timber floor houses (Breuer, 1988). That this is the only quantitative statistic that will be quoted here is indicative of not only the scarcity of hard data on the effectiveness of thermal mass as an energy saving measure in New Zealand but also of the relatively complex interdependencies of insulation, glazing, climate, heating regime and thermal mass.

In summary, then, thermal mass is in something of a "come-from-behind" position in terms of penetrating the New Zealand consciousness and becoming widely considered and adopted. Given an appropriately-raised profile (and possibly direct inclusion within the code), there is no reason why thermal mass should not receive much greater consideration in new house design and construction, particularly because the incremental increase in cost is insignificant in many instances (on flat sites a concrete slab-on-ground may be cheaper than a suspended timber floor). It is fortunate that those regions of the country where the relative mildness of the climate makes thermal mass most effective (the Auckland region, in particular) are those with the highest proportion of housing stock (present and likely future).

3.2 Barriers to the Use of Thermal Mass

Apart from the educational barrier referred to above, there are a number of practical and technical obstacles preventing the widespread adoption of thermal mass as a component of a strategy to improve the energy efficiency of New Zealand houses. Foremost amongst these is the fact that retrofitting the required quantities of thermal mass into an existing home is difficult, whereas incorporating it into a new home is comparatively simple and inexpensive, particularly if the major mass element is a concrete floor slab. Consequently, even if most new houses were to have much higher mass than has been traditional, it would be several decades before the majority of the total housing stock had been constructed along such lines.

The greatest potential for adding thermal mass to existing housing stock is in attached sunspace (greenhouse) additions where typically little or no thought is given to thermal mass considerations at present as mentioned in Chapter 2, "Solar House Design". Internal water storage is well-suited to retrofits in sunspaces, and possibly elsewhere in a house, but, apart from this possibility and the use of concrete in added areas, the opportunities in existing houses are rather limited.

Even for new housing stock, a concrete floor slab should have *at least* perimeter insulation added — not a significant technical difficulty in itself, but not standard New Zealand building practice at present. Furthermore, the thermal storage potential of the floor slab is significantly reduced by the insulating effect of the carpet that is invariably laid over it (Tucker, 1990).

Another possible argument against higher mass houses is that the inevitably slower response of such a house to auxiliary energy inputs might be undesirable for occupants who follow an intermittent heating regime — perhaps because the house is unoccupied during the day. Intermittency and unpredictability are well-known characteristics of weather patterns in New Zealand, and the thermal mass cannot be designed on the assumption that it will receive a predictable solar input each and every day.

Also to be considered are the earthquake risks that may be associated with attempts to incorporate significant mass above ground level, should that be desired or required. The necessary structural considerations may place high mass construction at a significant cost disadvantage in comparison with conventional timber framing in some situations (for example, a steep or inaccessible section). A masonry Trombe-Michel thermal storage wall might suffer a disadvantage in New Zealand in that respect, quite apart from other possible arguments against its widespread use because of time-lag characteristics (these, however, could be used to advantage — see Chapter 2). A Trombe wall's external aesthetics may not suit New Zealand tastes, and a large north-facing wall may interfere with household activities (e.g. ready access to outdoor living areas).

Finally, and very significantly, the need for and effectiveness of thermal mass is highly climate-dependent so that what might be an optimum amount and distribution of thermal mass in one particular location may be quite inappropriate in another location. For an environment in which the mean outdoor temperature is moderate but daily variations are large, thermal mass alone (without insulation) may be sufficient to satisfactorily temper the interior environment against the exterior extremes. That same strategy, however, would fail badly in a cooler climate. Thus the provision of the most effective amount of thermal storage is a relatively complex problem that requires knowledge and understanding if satisfactory outcomes are to be obtained consistently. In heat transfer terms, determining insulation requirements can be approached from steady-state considerations, whereas determining thermal mass requirements moves the building design into the more complicated realm of unsteady state.

3.3 Methods for Incorporating Effective Thermal Mass

Despite the barriers outlined above, there are a number of effective methods of incorporating thermal mass into new New Zealand houses. Some are already in common use, others can be implemented immediately, and the remainder are either futuristic or unlikely to make an impact.

For the purposes of this discussion, it is worth making a distinction between so-called *primary* mass (i.e. internal mass having a surface that intercepts solar radiation directly) and *secondary* thermal mass (which can only be heated by solar radiation indirectly via the combined processes of convection from the interior air and re-radiation emitted by primary thermal mass). Primary mass is much more effective in lopping solar-induced peak interior temperatures because secondary mass is largely reliant on an increase in air temperature if it is to gain energy. To some extent, some of this disadvantage of secondary mass can be overcome by providing it with a very large surface area so that only a small increase in air temperature is sufficient to bring about significant rates of heat transfer from the air into the secondary mass. Generally, though, it is considered unwise to be totally reliant on secondary mass for thermal storage in a winter heating regime.

Concrete Floor Slab

The use of a concrete floor slab is the most obvious method of adding thermal mass (part primary and part secondary) and has increasingly become the preferred floor construction method, albeit in most cases for economic reasons rather than to provide thermal mass. Unless there is a significant presence of groundwater movement, the current building code does not require that such slabs be insulated, and perhaps there is a case to be made for revising the code to include a requirement for at least perimeter insulation so that the thermal performance of the slab is enhanced and building heat losses are reduced.

The problem of the detrimental effect on slab storage that overlaid carpet causes (Tucker, 1990) can be overcome to a large extent through the use of alternative floor finishes such as slate or tiles. If these finishes are concentrated in the primary mass areas (i.e. along northern sides of rooms receiving sunlight through windows) and the floor carpeted elsewhere, the resulting compromise is aesthetically and practically acceptable to most people. Admittedly, such an approach does not overcome the problem of blockage of solar access to the floor slab by furniture positioned in front of glazing.

Internal Masonry Walls

If a floor slab is unable to provide sufficient thermal storage, the next most cost-effective method is generally internal masonry walls. Although unusual in New Zealand house construction, strategically-located masonry walls can provide additional mass that can take on a primary rather than a less effective secondary role when sun penetration is greatest in mid-winter (although achieving this may impose some limitations on north-south room dimensions). In many situations, tilt-slab construction may be more cost-effective for this than masonry block construction, but not all house builders have the necessary expertise and experience to undertake this at present.

In some houses, the addition of a brick or concrete block facing to a suitably located internal wall is one means of retrofitting some thermal mass (floor strength permitting, of course).

Room Ceilings

It has been suggested that locating significant primary thermal mass in the ceiling of a room (through, for example, the use of precast ceiling slabs) would circumvent the related floor slab problems of carpeting and furniture shading, but this would require, of course, means to direct incident solar energy upwards to strike the ceiling. One possible future technology solution to this might be through the use of holographic glass coatings that have a prismatic effect on sunlight penetrating a window. Apart from the possible thermal benefits of this, the holographic coating may be an effective means of achieving better natural light penetration into interior areas. It seems unlikely that this approach, if feasible, will have any significant effect before the year 2000.

Trombe-Michel Walls

Perhaps the best known of the outwardly-obvious thermal mass devices, Trombe-Michel walls originated in southern France and there are subsequent examples worldwide, including a few in New Zealand (the Forbes house in Kerikeri being perhaps the best known example in the New Zealand solar literature). There are variations on the basic theme:

- the wall may or may not have openable vents top and bottom between the living space and the solar-heated space between the wall and the glazing;
- the thermal storage medium may be concrete or water contained in tanks (as exemplified in "Sun Structure" homes); and
- the wall thickness may be quite large (to maximise storage) or less so if faster thermal response is desirable.

To obtain sufficient thermal storage, a Trombe wall may need to be of an area that would make it an unacceptably dominant feature of the house's northern aspect. Through having to sacrifice a significant proportion of northern wall area to accommodate the Trombe wall, the general New Zealand preference for significant northern window areas and/or ranchsliders to enhance indoor-outdoor living may be seriously compromised. If unvented, the heat release rate from the wall cannot be controlled and, regardless, night-time heat losses through the glazing can be significant. Earthquake considerations require that proper structural design of the wall be carried out, and thermal expansion may be sufficient to require particular design attention.

Considered together, these factors lead to the conclusion that Trombe-Michel walls are unlikely to be warmly embraced on a large scale by current and future designers of new houses in New Zealand.

However, a Trombe wall could be created in some retrofit situations by glazing an existing north facing masonry wall (and removing any internal insulation). More applicable to the New Zealand situation is the use of sunspaces, glazed areas large enough to provide sheltered living space adjacent to the house. Their efficacy can be increased by placing masonry in the wall between the sunspace and the house proper.

Water Storage

The high specific heat of water makes it a desirable medium for thermal storage, but, unlike concrete or brick, it does require a means of containment. In its crudest form, drums or plastic containers of water (treated with suitable chemicals to inhibit organic growth and corrosion if necessary) can be positioned in the house at locations where they will act as effective primary mass. Although this is more likely to be an acceptable solution in an attached greenhouse rather than inside the living space, it represents one of the few effective ways of adding significant thermal mass to an existing house and has the advantage over concrete of being able to store more than twice as much thermal energy in a given volume (for the same temperature rise). Outside of greenhouse retrofit and custom-designed Trombe water walls, opportunities for using water for thermal storage appear to be very limited, despite the fact that, unlike other materials (Lambourne, 1992), it has the desirable characteristic of negligible embodied energy (i.e. the energy expended in initially producing and putting in place the particular component). Water provides no structural or other functional contribution, so the costs of its containment and the interior volume sacrificed in using water storage must be totally assessed against the building's heating system.

Adobe/Earth Block Construction

In the relatively few examples of this type of house construction in New Zealand, it has invariably been an enthusiastic owner and/or builder who has given their time and energy to achieving effective thermal mass by truly traditional methods. Because of the relatively high labour component, the need for convenient access to soils/clays having the appropriate characteristics for this construction technique, the floor area penalty of the very thick walls and the relative lack of experience with the method in New Zealand, it is unlikely to make major inroads against "conventional" construction methods on a national scale. This is not to deny that it is a legitimate and well-founded method for introducing thermal mass (combined with insulative qualities) that results in attractive colouring and textures.

Subground Construction

It is well known that the daily variation in ground temperature is much less than the variation in air temperature.

Hence, designing the house so that it is surrounded wholly or in part by this more stable environment is favourable from the point of view of reducing internal temperature variations. Also gained is the possibility of intimate contact with thermal mass of very large magnitude. Whether or not this possibility should be taken advantage of is dependent on what the mean temperature of the surrounding ground is and what its thermal properties are. In many locations, proximity to groundwater may rule out this construction technique and, in any case, it represents such a radical change in both house and living styles that gaining wide acceptance by the New Zealand public is likely to be a slow process.

Rock Bed Storage

The necessary thermal mass may be in the form of bins packed with small rocks or stones, with the space air being passed through the bins (possibly with fan assistance) to give up energy to, or pick up energy from, the rocks as the situation requires. The bin itself may be a significant cost item (because of its size and structural requirements), and any fan and control system represents additional costs that most other forms of thermal storage do not incur. There is an advantage, however, in the occupants being able to exercise some control over when energy goes into and comes out of storage. As for adobe/earth block and sub-ground construction, the use of rock bed storage seems likely to be limited to enthusiastic owner/builders rather being widely accepted. To quote from Donn, 1990: “Research experience suggests that such devices are expensive toys. They lead to increased costs and complication for little return.”

Phase Change Material (PCM)

Because such materials utilise the large quantity of energy input or output when a phase change occurs, they have the potential to store large amounts of energy within a small volume of material and with little temperature change.

Although the basic chemical materials themselves may not be particularly expensive, it is necessary to add thickening and nucleating agents and package the PCMs in suitably proportioned containers to obtain the necessary consistent performance over the thousands of phase reversals expected of the storage medium during a building’s life. Overall costs, therefore, make them uncompetitive in comparison with conventional thermal storage materials at present, but this may change with large-scale production in future. Like water (but unlike masonry or brick), PCMs cannot make any structural or functional contribution to the building.

3.4 Control Aspects and Strategies

In a typical New Zealand house (without central heating) when the occupants leave the building, the heaters are turned off and the interior of the building cools down. Conversely, on returning to the house, heaters are turned on in the room or rooms being used. It is quite common for living areas (kitchen, family room etc.) to be heated whereas the rest of the house may be close to the outside ambient temperature. A difference of 15˚C between the air temperatures in different parts of a house would not be compatible with the efficient use of thermal mass in a house.

The same inertial characteristics that enable thermal mass to achieve a temperature-flattening effect can thus work against it in an intermittent heating regime or an extremely variable climate. If at any time the occupants require rapid space heating through supplying auxiliary energy input, the presence of thermal mass will have a pronounced slowing effect as some of the supplied energy goes into storage rather than heating the occupied space. That stored energy (which has been paid for) may be released back into the space in a totally uncontrolled manner at a time when the occupants may not derive any comfort benefits from it. This same uncontrollable characteristic can also mean that “free” solar energy may be released out of storage during unoccupied periods.

Sometimes overlooked in such criticisms of the effect of thermal mass is the fact that maintaining occupant comfort is only one aspect of interior temperature control; through filling in the troughs in indoor temperature variation, problems with moisture condensation and/or mildew formation can often be reduced in houses with adequate thermal mass (the need to avoid condensation and other means to achieve this are discussed in Chapters 4 and 6).

These arguments are similar to those that can be raised in favour of, or against, storage heaters utilising off-peak electricity, whether they be in the form of standalone appliances or heating cables embedded in a concrete floor slab. There appears to be scope for research into optimising the extent and location of thermal mass (included primarily for passive solar purposes) in conjunction with off-peak electrical storage heating since, to a large extent, the two energy input forms are available out of phase with each other.

Optimisation that shifts power demands off-peak is a valid strategy for lowering purchased energy *cost* and has the added benefit of reducing the national requirements for peak electricity demand, thereby postponing the need for an increase in installed generating capacity. On the other hand, simply shifting demand off-peak may not reduce the *quantity* of energy used to achieve particular comfort levels. Using good solar design to lower overall slab heating requirements as well as shifting the time of power demand provides both energy cost and quantity savings.

Recent Relevant Research Publications in New Zealand

Bassett, M R, R C Bishop and I S van der Werff (1990). *Annual Loss Factor Design Manual: An Aid to Thermal Design of Buildings*, Building Research Association of New Zealand, Judgeford.

Breuer, D R (1988). *Energy and Comfort Performance Monitoring of Passive Solar, Energy Efficient New Zealand Residences (2 vols.)*, New Zealand Energy Research and Development Committee Report No. 171.

Donn, M R and I van der Werff (1990). *Design Guidelines: Passive Solar in New Zealand*, Energy and Resources Division Report RD8831, Ministry of Commerce, Wellington.

Lambourne, R (1992). *Energy Embodied in Materials*, NZIA Environmental Policy Paper.

Tucker, A S and C J Dunlop (1990). *The Effect of Surface Coverings on Floor Slabs used for Thermal Storage*, Proceedings of the Australian and New Zealand Solar Energy Conference, pp. 323-330, Auckland.

Chapter 4
Insulating New and Existing Homes

4.1 Introduction

Insulating the building envelope (walls, floors, ceiling, etc.) helps to make a house more energy efficient and healthy. The energy objective of insulation is to reduce heat loss so that the thermal performance of the building can be better managed. The insulation level, thermal mass and degree of infiltration in a building, together with the occupier's choice and use of heaters, and the control exercised over ventilation, all interact to create the indoor climate.

If a building becomes too warm, due to solar heating, say, then heat can be removed through ventilation. If rooms are too cold they can be warmed by reducing the ventilation and using a heater. The amount of energy required from heaters to achieve a given level of comfort will be reduced if the building envelope is insulated. Some commentators have argued that increasing the level of insulation in older homes does not lead to a marked reduction in energy demand because the occupants take back some of the potential energy savings in the form of increased comfort levels. This issue is discussed in the last section of this chapter.

An important first step with both new and, especially, older homes is weatherstripping to reduce unmanaged loss of warm air and infiltration of cold outside air into the home. An overview of weatherstripping is presented below. It is important, however, that a house is adequately ventilated and the means to achieve this without unduly compromising energy efficiency is covered in Chapter 6 "Ventilation in Homes".

In an uninsulated home, it may be possible to keep rooms generally warm enough through reducing draughts, limiting ventilation and using heaters frequently. This will be expensive and the lack of ventilation is a health concern. This concern is compounded by the likelihood that, in parts of the building, the heat gradient across the walls will be so sharp that condensation occurs inside the home. This can damage paint and furnishings directly or, through growth of mildew and mould, make the home unhealthy.

As discussed in the General Introduction and Overview, only about a third of New Zealand homes have been built to meet current insulation standards. A fraction of the balance may have had a degree of insulation retrofitted. The priority in a relatively draughtproof home where ventilation can be managed, is ceiling insulation, followed by insulation of the walls, windows and then the floor (refer to Figure 1.5). Weatherstripping and ceiling, wall and floor insulation are discussed in this chapter. Window insulation is discussed in Chapter 5 "Efficient Windows and Glazing".

Some of the heat loss from homes occurs through convection and so the siting of the house and its immediate environs can affect its thermal performance. Placing a home so that it is sheltered from prevailing winds could be a useful strategy. Making use of trees and adjacent structures may also be practical. Common sense is needed to avoid siting problems such as excessive shading. The issues related to siting were discussed in Chapter 2 "Solar House Design".

4.2 Weatherstripping

Draughts make a home uncomfortable and are one of the major causes of heat loss. A well insulated but draughty home could lose up to a quarter of its heat through tiny gaps and cracks around doors and windows, through the floor, etc. Figure 4.1 shows the major sources of heat leaks and draughts in a home. Sealing these leaks can save energy. It is important, however, that problems due to inadequate ventilation be dealt with as part of a weatherstripping exercise.

Mould and damp can be signs of poor ventilation as well as lack of adequate inside temperatures. Kitchens and bathrooms in particular should be fitted with extractor fans or other forms of manageable ventilation to remove moisture. Natural gas stoves and portable LPG space heaters release significant amounts of moisture into rooms. In some cases, the source of inside moisture may be damp underfloor conditions caused by groundwater, lack of air flow under the house, etc. Weatherstripping without paying attention to sources of moisture and providing adequate controllable ventilation could compound damp and mould problems.

The technology of weatherstripping is a large subject and the discussion that follows is only intended to cover the main points.

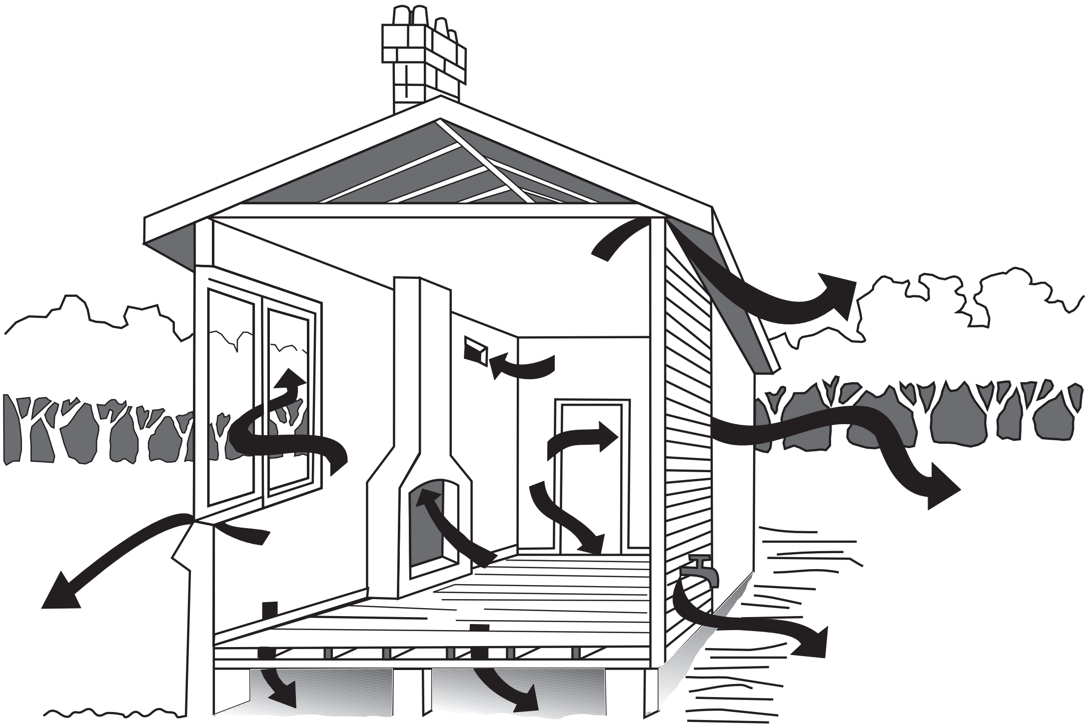


Figure 4.1: Major sources of heat leaks and draughts (Ministry of Energy, 1983)

Windows and Doors

Doors let warm air out of the home whenever they are opened. Creating an enclosed porch to act as airlock can significantly reduce this loss. A number of proprietary draught excluders are available to reduce the infiltration of air under doors. When correctly fitted, they do not interfere with the operation of the door. They generally use either rubber material or bristles to create a seal. Less convenient floor dogs (sausages or snakes) can be made and placed against the bottoms of doors.

Gaps are usually present where doors and windows butt against their surrounding jams. A variety of materials can be used to provide a seal with the jam. Polyurethane self-adhesive foam has a short life and is difficult to clean. PVC or vinyl foam is superior on these grounds. All self-adhesive foams will only remain on suitable surfaces: clean, smooth and not prone to condensation. The use of draught stop materials may be futile if the door or window really needs to be rehung or the window glazing is loose or cracked.

Cracks and Gaps

Rubber underlay beneath carpet can help deal with small cracks in tongue and groove flooring. Cracks around window and door frames, in the corners of walls and around service holes (water and power) can be sealed by using suitable caulking materials. New water cleanup materials are now available that make the job easier than before. The main barrier to infiltration has been found to be the inside lining of a house rather than the outside, so the inside barrier should be sealed first. This will also help to prevent the movement of moist air from the living areas into the wall cavities where it could condense and create a problem. Caulking large outside gaps can be helpful once the inside has been thoroughly sealed.

Stoves and Chimneys

Chimneys are major sources of warm air loss from a house. Open fireplaces are not efficient in terms of the amount of heat they produce for the fuel they use (refer to Section 9.3 of Chapter 9 "Solid Fuel Heating"). They may be retained for the occasional pleasure of an open fire, but steps should be taken to reduce the draughts they cause. If a chimney is no longer used, then it should be blocked off, preferably with a weatherstripped cover that fits over the fireplace. If it is used, then a removable cover could be made. If the fireplace has a damper fitted, then closing this when there is no fire will reduce draughts.

Enclosed burners are more energy efficient than open fireplaces (Chapter 9). Open fires and enclosed burners both require an air supply and, if this is drawn from the room, then warm air will be lost. An adjustable air vent placed in the floor immediately adjacent a heater or fireplace will enable a degree of outside air to be used for combustion instead of warm inside air.

4.3 Types of Insulation

Figure 4.2 shows the heat movement through a standard wall. Similar processes occur through floors and ceilings. Still air is a good insulator providing convection currents are avoided. Generally, air gaps up to 100 mm wide provide some insulation effect, but not enough. Most forms of insulation reduce the rate of conduction and convection heat loss through the building envelope. They can do this by using a low conductivity material, such as a solid foam, that blocks all air paths to avoid convection loss.

Alternatively, a reasonably conductive but economic material can be configured to provide effective insulation. A fibreglass blanket is an example. The interconnected glass fibres create a long conduction route that slows the rate of heat transfer while convection is reduced because the fibres create still air surface layers and provide a barrier to air flow.

Heat is also carried from the inner to outer surface of the building envelope by radiation. Reflective materials, such as aluminium foil, can be useful on the inner surface to reduce this loss. These materials work on the basis that warm, shiny surfaces do not radiate heat as quickly as dark surfaces. Consequently, they should be placed with the shiny side facing out. Furthermore, a still air gap of at least 20 mm is needed in front of the reflective surface. In practice, this means the foil is placed under the wall lining with the shiny side facing the cavity.

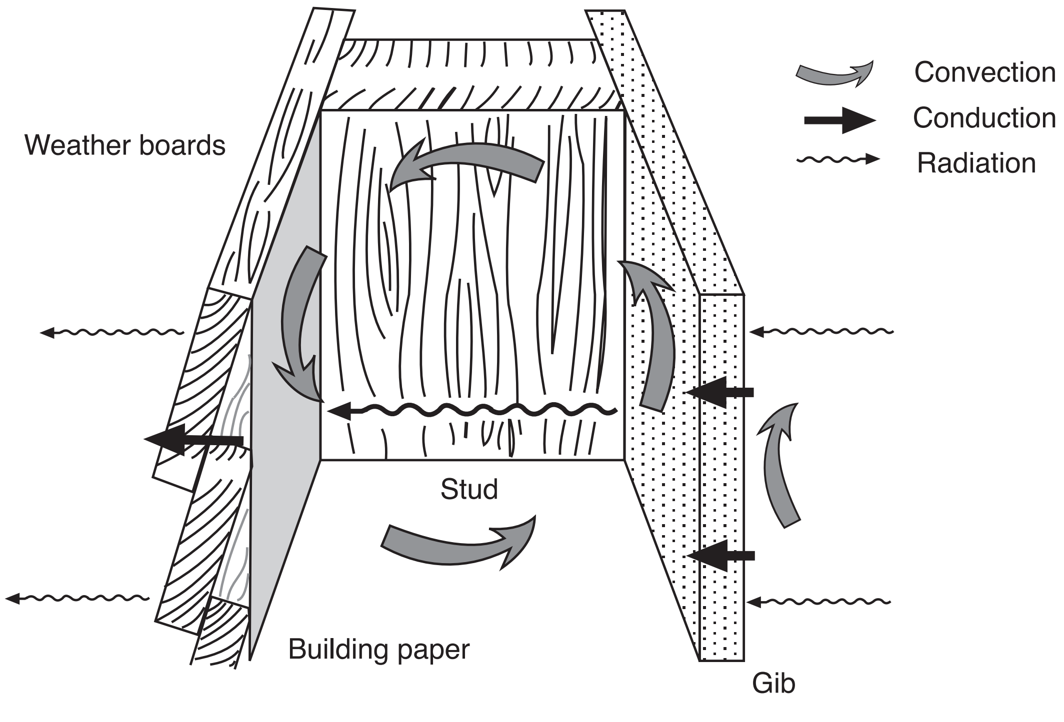


Figure 4.2: Heat movement through a wall (Ministry of Energy, 1983)

Aluminium foils are not as effective as materials that prevent convection and conduction across the inner and outer surfaces.

There are four basic types of insulation material. The earliest of the modern materials is reflective aluminium foil. This no longer satisfies the insulation requirements of the New Zealand Building Code, except for floors, and then subject to certain conditions (see below). The second type of insulation is bulk fill materials. These are designed to fit between the wall studs and drape over, or fit between ceiling joists, or otherwise fill building cavities. The best known example is fibreglass batts and blankets. The third type is loose fill materials, which are blown into ceilings or sprayed into wall cavities. Cellulose fibre is a common example of this type. Finally, there is solid insulation that clads or forms an integral part of the building envelope. Examples include rammed earth construction and polystyrene materials.

Bulk Fill Materials

The cheapest and most common type of bulk fill material is fibreglass. It is available in various thicknesses, cut into segments to fit into wall cavities or available as rolls for roof and ceiling insulation. This material is fireproof and stable, but it needs to be handled carefully to avoid skin and respiratory tract irritation. There is concern that long term exposure to the glass fibres could cause asbestos-type problems, but this has not been confirmed. With proper installation, glass fibres should not move from building cavities into living spaces.

Wool, polyester and mix blend blankets provide an alternative to fibreglass. A New Zealand-developed wool product that overcomes most of the problems inherent with fibreglass is available. A treatment process is used that maintains the loft and increases the fire retardancy of the wool, and also deodorises and mothproofs it. The ability of wool to absorb and release moisture may play a role in building temperature regulation, particularly in hot climates where insulation is used to keep heat out. This issue is under scientific study in Australia. Both wool and polyester can be bonded to aluminium foil or building paper. Wool and polyester materials will not ignite, but they will burn in an established fire.

Solid Materials

Polystyrene foam provides a rigid insulation. It can be cut to fit into building cavities, although obtaining a tight fit can be difficult. Better uses for polystyrene present themselves. It can be used as an external cladding, with the outermost surface covered in a fibreglass-resin material, or a reinforced plaster system. An advantage of having the insulation on the outside is that thermal bridging is minimised. In a conventional system, timber framing and gaps in fibreglass insulation create these bridges. When used to clad the exterior of a concrete block wall there will be a significant gain in the thermal mass of the building.

Polystyrene can also be used to line the inside of concrete block walls. The interior can then be finished with another lining such as foil-backed gib board. Another use for polystyrene sheets is as insulation underneath and around the edges of concrete floor slabs. This is particularly important if underfloor heating is proposed.

Several new uses for polystyrene have been developed. One is a lightweight concrete building block with a polystyrene insert inside the block. The space left inside the block allows enough room for reinforcing and sufficient concrete to be poured to meet most house structural applications. The R value of this block is R0.75 compared to a traditional block's R0.1 to R0.3 (the larger the R value the better the insulation). On its own, the new block may not be sufficient to meet the requirements for walls (see below), but it may comply in conjunction with an airspace created by wooden battens and foil-lined gib board lining. Table 4.1 shows the R value for several common construction materials. Many householders think that brick or concrete is a good insulator. As mentioned earlier, these materials are useful as thermal mass, and part of the reason is because they are not good insulators — they absorb heat readily.

Another novel use is to create hollow interlocking blocks out of polystyrene. These blocks can clip together to form a wall similar to a concrete block wall. The hollows are filled with reinforced concrete and the outside is covered in one of the systems used for polystyrene exterior cladding. The inside can be plastered or have a lining bonded to it. The resulting R value is R3.0, a very high value for a wall. Polystyrene is treated to avoid accidental ignition, but once it is on fire it burns with a dense acrid smoke.

Timber is not a very good thermal insulator. If the timber is thick enough (around 200 mm) then a solid timber home may provide adequate insulation. The cost of timber is usually a limiting factor, but in cases such as log cabin construction, an adequate average thickness may be practical. Materials such as adobe and rammed earth walls can provide adequate insulation if they are very thick. Subground construction can also reduce insulation requirements, but attention to groundwater control is essential.

Building Material 100 mm thickness	**R Value** $m^2.^{\circ}C/W$
Clay brick	0.1
Concrete block	0.1 - 0.3
Plasterboard	0.5
Softwoods	0.8

Table 4.1: Construction material R values

Loose Fill Materials

These consist of insulation particles that are blown or sprayed into place. Quick setting adhesive is usually used with loose fill placed into wall cavities to prevent settling. The two most common types of loose fill are cellulose fibre in the form of macerated paper (often recycled paper) and mineral fibre. Mineral fibre is made by melting selected minerals and spinning them into fibres. These fibres are short and loose rather than long and matted, as is the case with fibreglass. Waste from fibreglass manufacture can be used to produce a loose fill product. Polystyrene beads can also be used as loose fill.

Loose fill materials are arguably best suited to ceiling insulation and retrofit wall insulation. Cellulose is quite cheap, but can settle or blow about in draughty ceilings. It can also absorb moisture (relatively dry paper is around 10% moisture). This can make the insulation corrosive to metal fittings. These problems can be avoided with appropriate treatment and placement of the material. Cellulose used for insulation has a fire retardant added during manufacture.

Mineral fibre is more expensive than cellulose but will not burn, smoulder after a fire, settle or corrode metal fittings.

4.4 Insulation Requirements

As outlined in Chapter 1, new houses in New Zealand must comply with NZS 4218P. The standard specifies a set of R values for walls, floors and roofs for different types of construction. If more insulation is placed in the roof, then less is required in the walls and vice versa. The Standard is under review and one possibility is to vary the requirements according to the climatic zone.

The new Standard may also allow the designer to trade off special building features, such as passive solar gain, against insulation levels. A lower bulk insulation level could be compensated by orienting the house for maximum solar gain, having additional double glazing or including thermal storage mass in the design. Such flexibility would allow a high degree of architectural freedom of expression while still ensuring a home was an efficient energy consumer.

At the moment, the minimum R value for floors is R0.9, which can be meet by underfloor foil. In standard construction, the R value for timber-framed walls is R1.5, which can be satisfied by having around 75 mm of polyester, wool or fibreglass bulk product in the cavity formed by normal studs. In most cases (depending on roof type and wall insulation), an R value of R2.0 for the roof will ensure compliance. In a draughtproof home, especially in colder areas, it will be cost effective to go beyond the minimum requirements (in a draughty home air infiltration, rather than insulation, will be a critical factor). An R value of R2.0 can be achieved by filling the wall cavity created by normal studs 94 mm thick). It will generally be beneficial to increase ceiling insulation to R2.4 or R3.0. The latter requires about 150 mm of bulk insulation, which could be a problem with some skillion roofs.

R values are determined on the basis that there is still air around the insulation. It is important that draughts in ceilings and airflow between wall claddings and insulation be minimised. Well-installed building paper or solid sheathing (such as plywood) can help prevent air blowing around inside the wall cavity. This is especially important with non-sheet claddings such as weatherboard, board and batten, shiplap, etc. In the case of skillion roofs, an air gap is desirable to reduce condensation under galvanised iron, but the ceiling insulation can still be sealed with building paper.

All insulation should be installed so that:

- there are no gaps — even small gaps around the edges can greatly reduce the insulation value;
- the minimum thickness of the insulation should be maintained — areas of blanket materials flattened during installation should be relofted and care is needed to obtain uniformity with loose fill materials; and
- the material should not be crushed, creased or torn, nor installed if it has become, or could become wet — even fibreglass can settle if it is soaked.

BRANZ Bulletin 292 details more fully the requirements for thermal insulation of houses. Bulletin 287 describes external insulation and finishing systems. A Ministry of Commerce publication on construction issues for passive solar in New Zealand also provides important information on insulation detailing to gain the best thermal effect, such as by avoiding thermal bridging (Donn, 1990).

4.5 Application of Insulation Materials

Table 4.1 shows the normal applications in new houses for the most common types of insulation (BRANZ, 1993). Table 4.2 shows the main insulation brands available in New Zealand, the range of products, applications, R values and 1995 prices (Consumer, 1995). Of the products surveyed, cellulose and mineral fibre loosefill are the most cost effective materials for roof insulation, while fibreglass is the cheapest wall material. The prices shown are only indicative and should be checked against local conditions, opportunities for bulk purchase discounts, etc. The strengths and weaknesses of different types of insulation also need to be considered by architects and homeowners.

Insulation material	Where installed	When to install
Fibreglass segments	floor cavities	after building is completed
	wall or roof cavities	before fixing linings
	ceiling spaces	after lining the ceiling
Aluminium foil (1)	directly behind wall lining with shiny side facing cavity	before or with linings
Perforated aluminium foil	suspended timber floors draped over top of the floor joists	just prior to laying flooring
Polystyrene boards	to external walls as an insulation	after framing is completed and fully braced (2)
	wall and roof cavities	before fixing linings
	under concrete slabs	after laying the damp-proof membrane and before placing the concrete
	ceiling spaces	after lining the ceiling
Macerated paper, wool, fibreglass fills	ceiling spaces	after lining the ceiling

NOTES:
(1) Aluminium foil alone does not satisfy the insulation requirements of the New Zealand Building Code Clause H1 Energy Efficiency.
(2) External polystyrene insulation must be overcoated with a proprietary plaster system and a weather-resistant coating.

Table 4.2: Installation of insulation materials (BRANZ, 1993)

Typical Brands	Material	Type	Where used	Typical R value	Approximate installed cost (per m^2)
Insul-fluf, Super-fill, Acrofibre	Cellulose fibre (macerated paper)	Loose fill	Ceiling	2.2 (100mm)	$5.10
Rockwool	Mineral fibre	Loose fill	Ceiling	1.9 (100mm)	$6.50
Pink Batts,	Fibreglass	Blanket	Walls	1.8	$8.30
Manville,			Ceiling	2.2	$9.50
Redicut,			Ceiling	2.4	$9.60
Bradford			Ceiling	3.4	$13.05
Comfort Zone,	Polyester	Blanket	Walls	1.6	$9.70
Dacron,			Ceiling	2.2	$14.00
Polartherm					
Thermofleece,	Wool	Blanket	Walls	1.7	$10.40 $17.80*
Wool line			Ceiling	2.2	$11.80 $19.50*

*Thermofleece cheaper; Wool line more expensive

Table 4.3: New Zealand insulation products, performance and costs (Consumer, 1995)

The issues involved in floor, wall and ceiling insulation, in both new and existing houses are discussed below.

Underfloor Insulation

In a new house, underfloor insulation is easy to install. The standard approach for suspended timber floors is to drape perforated aluminium foil across the floor joists. A midspan sag in the foil of 75 mm will achieve an R value of R0.9, but increasing the sag to 100 mm is recommended. This increases the R value and can help compensate for some shortcomings in installation. Efforts should be made, however, to avoid shortcomings: attention should be paid to an adequate lap between foil sheets (100 mm minimum) and penetration for services should be sealed with aluminium adhesive tape, etc. Floors exposed to wind (e.g. pole houses or windy sites) should be lined with a suitable sheet material along the underside of the joists. The sheet should be perforated where there are water pipes, bathrooms etc. above.

With an existing home, an underfloor insulation retrofit may not be worthwhile, especially if the floor is not exposed to wind and is covered in carpet or cork tiles. If the floor is old, with tongue and groove boards with fine cracks to let air in, then some action may be warranted. The simplest and cheapest approach is to secure perforated foil under the floor joists using light wooden battens or a plastic strip stapled to the joists. The battens or strips help to spread the load on the foil and thus prevent wind damage. They may not be needed if the floor is covered by a sheathing or is protected from the wind by a solid foundation wall. Fibreglass batts can be placed between joists and held with sheet material across the joists. Foil-faced fibreglass and proprietary segments with attached paper stapling tabs are available to enable installation without a sheet lining.

Wall Insulation

Foil insulation alone does not satisfy the current New Zealand standard. It can still be used, but only in conjunction with another material, such as polystyrene. Installing bulk fill materials is straightforward during new construction, but may not be suitable as a retrofit option.

When insulating an older house there is currently no requirement to comply with the Building Code's thermal standards. Loose fill material is suitable in retrofit situations, as it can be pumped in through holes cut in either the lining or exterior cladding, but it can be difficult to completely fill the wall cavities. It is important not to be mislead by the attitude that some insulation is better than none. It might be, but not by much, and quite possibly the benefits of a second-rate insulation job will not be commensurate with the costs.

If a retrofit is part of a renovation project, then consideration should be given to removing the wall lining (or exterior cladding) to ensure the wall is properly insulated. On the other hand, whenever a renovation project exposes the cavities of an external wall, insulation should be installed.

Ceiling or Roof Insulation.

This is the most important area of a house to insulate and should be the first priority in an uninsulated house. Both bulk and loose fill materials can be used. Bulk fill material can be cut to fit between the ceiling joists or purlins (skillion roof). Alternatively, blankets can be draped over ceiling joists, which helps to reduce conduction of heat through the timber. It is important that the edges of blankets be sealed (usually by jamming against part of the ceiling construction) so that air cannot run along the underside of the blanket and then escape. Insulation should extend to the outside edge of the walls, but there is no advantage in covering eaves.

Loose fill materials are fairly easy to place in ceilings, but it is important to obtain a uniform coverage. The material can be built up above joist level to help reduce heat loss through the timber, although this can make access through the ceiling space difficult later on. Ceiling spaces should be draughtproof at least to the point where the material does not move about. It is easy to disturb material when working in the ceiling space and the need to restore the insulation should be considered when finishing up.

Several problems or special considerations arise with ceiling insulation. With skillion roof construction, it is important that the insulation does not completely fill the roof cavity. A small gap of around 25 mm should be left at the top of the insulation to provide for cavity ventilation to remove moisture (but the top surface of the insulation can be covered in building paper to reduce heat loss or insulation disturbance from draughts). Insulation around chimneys and flues must be completely fireproof (fibreglass or mineral fibre).

The heat generated by recessed incandescent ceiling lights is usually vented into the ceiling space and overheating and fire risk can occur if insulation is placed over the lights. This type of light is not energy efficient because of the chimney effect it creates as well as its poor electricity to light conversion factor. Recessed compact fluorescent lights are available that generate little heat and can generally be covered with insulation (heed the manufacturers instructions). Some homes also vent steam from the kitchen or bathroom into the ceiling space. This is not wise as the moisture will condense on colder surfaces about the insulation and this can be detrimental to ceiling timbers and some types of insulation, particularly cellulose fibre loose fill. Extractor fans should vent directly outside, through a wall or roof cowling.

The roof space above an insulated ceiling can become very warm when the sun shines on certain types of roofing, particularly galvanized iron products. This has led to a number of proprietary air heat recovery systems. These take the warm air from the ceiling space and gently blow it into the house. The positive pressure is thought to drive out cold damp air and help make the home more comfortable and less prone to mould, etc. When fibreglass is used as ceiling insulation, it is very important that these systems have adequate filters that remain effective given typical householder attention to maintenance. As mentioned earlier, there are concerns emerging over the health safety of long term exposure to fibreglass fibres. This concern could be mitigated by placing building paper over top of the ceiling joists to seal the fibreglass insulation.

4.6 Alternative Insulation Materials

There is a trend in architecture to use sustainable materials, natural renewable materials, materials with low risk of contributing to indoor pollution, etc. Historically, a wide range of natural materials have been used for insulation, such as reeds, wood shavings and cork. As well as providing an adequate R value, insulation must satisfy a number of other criteria, such as:

- resistance to insect attack and decay;
- will not harbour vermin;
- is not easily ignited and is fire resistant;
- can withstand occasional wetting from storm leaks;
- is easy to store and install; and

- has limited hygroscopic properties.

Natural materials such as wool and cellulose can be treated to satisfy most of these criteria. In the future, other natural materials, such as coconut fibre or seagrass, may be used for bulk insulation as well as floor coverings.

In some cases, natural and synthetic materials can be combined to provide the right blend of properties. Wool and polyester bulk fill is an example. Meanwhile, the development of synthetic insulation materials is continuing. For example, lightweight foamed concrete or the incorporation of insulating additives to cement render may become mainstream building materials.

The most effective insulation is a vacuum. In the United States, lightweight vacuum panels have been developed for household refrigerators and freezers. In time, this type of technology may be cost effective for modular house construction, especially in very cold areas where otherwise very wide studs (or extra timber for battens) would be needed to create wide enough insulation cavities.

4.7 Insulation and Energy Demand

There is evidence that, in some cases, when old homes are insulated, occupants use heaters more than before. Not all the energy savings expected materialise. It is not likely that the occupants are now enjoying excessive comfort. It is more likely that previously the house was too cold, and the cost of heating the uninsulated, draughty home was prohibitively expensive. Once the house is retrofitted, the extra cost of obtaining a healthy environment becomes manageable.

Energy efficiency is about getting an energy service for the least energy input. After installing insulation, some people redefine the service they want. As a society, we may be in the process of redefining the minimum space heating service acceptable in our homes. In that case, insulation will help to reduce the amount of energy input needed to achieve the minimum service.

There is a growing awareness that many New Zealand homes are underheated. They are too cold and damp, especially for children and the elderly. A number of studies are underway into possible links between indoor climate and health issues such as asthma. This concern could be addressed by putting more heat into buildings, although for some people financial assistance with power bills would be needed.

Insulation has to be seen in the light of the need to improve our housing stock and make it more suitable for habitation. If we need warmer and drier homes, then draughtproofing, insulation, double glazing, passive solar retrofits, etc. will enable this to be achieved with less use of electricity, natural gas, etc.

References

Building Research Association of New Zealand, *BRANZ Bulletin 287— External Insulation and Finish Systems*.

Building Research Association of New Zealand, *BRANZ Bulletin 292— Thermal Insulation of Houses*.

Building Research Association of New Zealand (1993). *BRANZ House Building Guide*, Wellington.

Consumers Institute (1995). *Consumer*, No. 335, March 1995.

Donn, M R, I van der Werff and G Miller (1990). *Construction Issues: Passive Solar in New Zealand*, Energy and Resources Division Report RD8832, Ministry of Commerce, Wellington.

Ministry of Energy (1983). *How to Heat Your Home*, published by the Ministry of Energy and Asia Pacific Economic News, Wellington, 1983.

Chapter 5
Efficient Windows and Glazing

5.1 Glass and Insulation

This chapter is concerned with energy efficient windows. Double glazing is discussed in detail and alternatives to double glazing are briefly mentioned. Glass technology and surface coatings are also discussed.

Windows form an important function in house design. They admit light and solar heat, provide a view of the environment and, in most cases, can be opened for ventilation. Window shapes, size, orientation and frame colours provide designers and owners with a range of options, but when it comes to glazing options, there is a saying "People look through glass, not at it". This is especially applicable when considering the energy efficiency of window design and, therefore, windows are becoming the weakest link in the thermal insulation of a modern building.

BRANZ bulletin 292 indicates that 24% of the heat loss from an uninsulated house is through the windows (12% through the glass and 12% from ventilation losses). However, this figure increases significantly once all or part of the roof, floors and walls are insulated, and it is not unusual for half of the conduction losses to be through single glazed windows. This, in combination with the New Zealand trend to use large glass areas in housing design, makes glazing an important element in an energy efficient home.

Traditionally, glass in New Zealand houses has been thin sheet glass, and more recently high-quality float glass. Many original New Zealand bungalows and villas have very thin 2 mm sheet glass (often as small panes). This has increased over the years to 3 mm sheet and float glass, and now many modern houses are using only 4 mm and 5 mm float glass. The glass thickness for houses is normally determined by windload and human impact requirements in relation to the sizes of windows and doors, hence as the glazing area in houses has increased, the thickness of the glass used has also increased. The problem with single monolithic glass is that the thickness makes no real difference to the thermal insulation of the building. Single glazing with 3 mm glass has a U value of around 6.3 W/m^2°C, while 6 mm glass has a U value of around 6.1 ($R \cong 0.17$).

There are several ways to improve the insulation of windows, the most common being the use of blinds, drapes and curtains. These are variable insulation products as they only work when installed and positioned correctly, and there are such a wide range of options available. A major problem with these products is that many consumers do not appreciate how a blind or a curtain acts as an insulating medium, and do not provide a sealed air space between the glazing and the blind. In addition, there is very little data giving thermal performance of these products, and consumers don't question whether the product really works or not — they just buy "thermal drapes".

The second product that is less common but more effective is double glazing. Recent estimates indicate that only 7% of domestic windows are double glazed, although this trend is increasing due to the increased awareness of energy conservation.

5.2 Double Glazing Overview

Double glazing is quite simple — windows have two pieces of glass with an airgap between. The amount of spacing between the panes and the method of spacing them depends on the application. Large air spaces up to 300 mm are often required for acoustic purposes, and these are created using double sash systems. One or both of the sashes may open to allow cleaning because the sealing of large air spaces is difficult over a long period of time.

The most common form of double glazing is a Sealed Insulating Glass Unit (SIGU), more commonly called an Insulating Glass Unit (IGU). An IGU uses a proprietary sealant to seal the two or more panes of glass together and most commonly has an airspace between 6 and 12 mm. The definition of a Sealed IGU, according to ASTM E774 (American Society for Testing and Materials), is "A preassembled unit, comprising organically-sealed panes of glass separated by dehydrated space(s) intended for vision areas of buildings".

The concept of insulating glass as a means of conserving heat has been in existence since the 1920s. However, organically-sealed Insulating Glass Units did not emerge until the late 1950s, and were first made in New Zealand in 1965. Since that time, energy conservation and insulation have become major issues in domestic and commercial glazing, and the market place has witnessed a tremendous increase in the need and use of Insulating Glass Units.

Benefits of Insulating Glass Units

Insulating glass units:

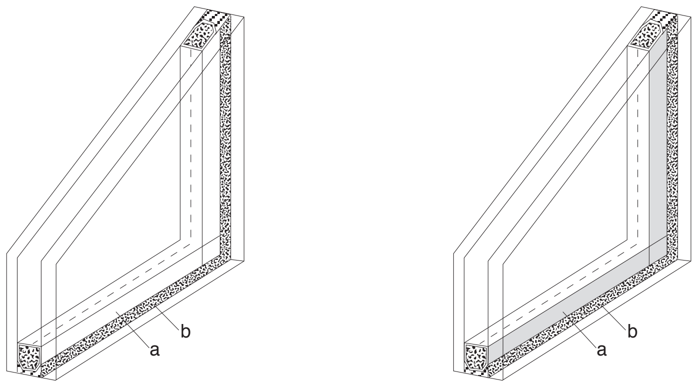
- improve the comfort of occupants by reducing the cold zones near windows;
- reduce the incidence of condensation, which can obstruct the view and damage woodwork, decorations and curtains;
- reduce heat buildup in summer and reduce loads on air conditioning equipment;
- reduce noise transmission and provide a more peaceful working environment;
- reduce the need for thermal drapes that can obstruct picturesque views;
- provide added protection against burglars;
- increase the windload resistance of the glazing;
- reduce ultraviolet transmission which assists in protecting carpet, drapes and furniture from fading (depends on glass type and thickness); and
- are versatile — individual performance requirements for safety, security, solar and sound control can be achieved according to the selection of glass type, glass thickness and airspace.

There are two traditional methods of making IGUs — the single seal system and the dual seal system (see Figure 5.1(a)). The difference between the two is that the dual seal system contains an inner seal (between spacer and glass) in addition to the outer edge seal. Both single and dual seal systems have proved their long term reliability over many years and are capable of meeting most international standard requirements. Provided that the glazing system is adequate, a good single seal unit will give excellent service and use, although a good dual seal unit will be even better. Dual seal systems became available in the 1970s, and there has been an international tendency to use dual seal systems in recent years, particularly with the advancements in automated production and their ability to consistently outlast single seal units, both in testing and service.

Conventional single and dual seal IGUs are made using aluminium spacers to separate the glass. These spacers are joined in the corners with specially designed corner keys, which are either plastic or metal depending on the system. In some high quality systems, the corners are notched and bent in one piece and are ultrasonically soldered to overcome the inherent weak point that the corner creates. The aluminium spacers are filled with a desiccant that absorbs water and chemical vapours inside the unit. Normally, only the two long sides of the unit are filled, but this depends on the design and manufacturer's requirements. The types of sealant used for the single seal systems are normally polysulphide, polyurethane and hot-melt butyl. For a dual seal system, the primary or inner seal is either butyl or polyisobutylene. The outer seals or secondary seals are polysulphide, polyurethane, hot-melt butyl or silicone.

Two rival technologies have evolved for sealing IGUs — thermoplastic versus the thermosetting sealants. These technologies offer competing sets of benefits, disadvantages, etc., and the choice has largely been with the IGU unit manufacturer based on their need to match a system to their production needs and/or product line. Thermosetting technology uses chemistry that cross links or cures into a nonreactive state. Products such as polysulphide, polyurethane and silicones are categorised as thermosetting. Thermoplastic materials, such as hot-melt butyls, polyisobutylene and combinations thereof are noncross-linked and are typically applied in heated form, which sets when it cools.

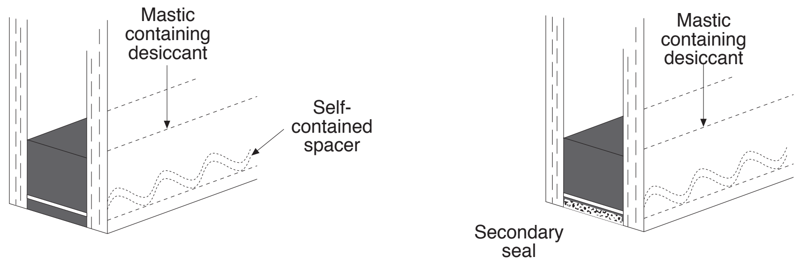
The 1980s has seen new technological advances in IGU technology and the release of proprietary systems. The most common is the Tremco "Swiggle Strip" system. Swiggle Strip is an extruded butyl-based tape of quality thermoplastic compound, which contains a corrugated aluminium spacer and molecular sieve desiccant. It, therefore, combines conventional components into one tape. Swiggle Strip was patented in 1979 (Figure 5.1(b)). The Swiggle Strip System is also available in dual seal configuration (DS), where the secondary seal of silicone is used to strengthen large units or units under high design loads. The high modulus silicone seal also allows for better butt-jointing adhesion and compatibility (Figure 5.1(c)). The standard Swiggle Strip unit can be expected to perform as well as, or better than, a conventional dual seal unit.



Single seal units with hollow spacer frame
(a) Hollow spacer frame containing desiccant
(b) Liquid applied, chemically curing sealant; or solid applied, heat activated butyl-based sealant (commonly described as "hot-melt sealant")

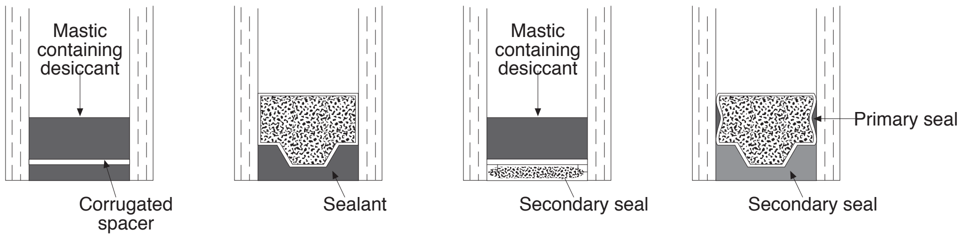
Dual seal units with hollow spacer frame
(a) Hollow spacer frame with low moisture vapour transmission primary seal applied to the side of the spacer in a continuous bead.
(b) A secondary, liquid-applied, curing sealant used around the outside of the spacer.

Figure 5.1(a): Traditional methods of making IGUs



Standard Swiggle Strip® **Swiggle Strip ® D.S.**

Figure 5.1(b): The Swiggle Strip System



Swiggle Strip® single seal **Conventional single strip** **Swiggle Strip® dual seal** **Conventional dual seal**

Figure 5.1(c): Swiggle strip vs conventional single and dual seals

5.3 Thermal Performance of Windows

It is important to understand the heat flow through insulated glass units and the technology available that affects this heat flow. In simple terms, heat flows “from where it’s hot to where it’s not”. That is to say, heat travels from areas of high temperature to areas of low temperature. In the winter, heat is moving from within our homes to the colder outdoor environment. The majority of this heat transfer will occur across the path or paths of least resistance and areas of high heat concentration to areas of low heat concentration.

There are four ways that heat travels through an IGU (Figure 5.2). Heat travels as long-wave infrared radiation through the airspace of the IGU. Solar heat from the sun hits objects outside and radiates through the windows. Heat also radiates from objects within the home (including people) and travels out through the windows. Heat can also travel directly from object to object if its energy is transferred from molecule to adjacent molecule — again moving from areas of high heat concentration to areas of low concentration. This phenomenon is known as conduction — a material’s propensity to allow heat to move through it is, therefore, known as conductivity. The third way heat travels through an IGU is via convection. Convection is the movement of warm air across space displacing cold air and transferring heat to adjacent surfaces. Think of it as a warm air current that moves heat more rapidly across a wide air space than conduction can alone. Convection is largely suppressed in narrow spaces, such as an IGU and, therefore, conduction can become the dominant heat transfer mechanism.

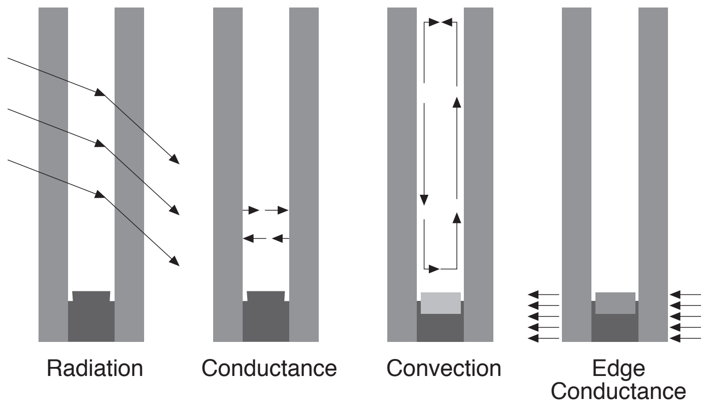


Figure 5.2: Efficiency robbers

Since heat will take the path of least resistance, the presence of a highly conductive space system at the IGU edge can mean a thermal short circuit. Thus, the fourth energy robber is heat conduction at the edge through the components making up the insulating spacer/sealed system (and possibly the accompanying window frame). The IGU can be thermally reinforced by using Low E glass and/or Argon gas in the “air” space. These energy savers are shown in Figure 5.3. Low emissivity glass is an example of a product that can be used to control heat radiation. The basic idea is to reflect radiation back to its source; therefore, heat is reflected back to the outside in the summer, and back into the home interior in the winter. (For more information refer Attachment 2, Low-E High T.)

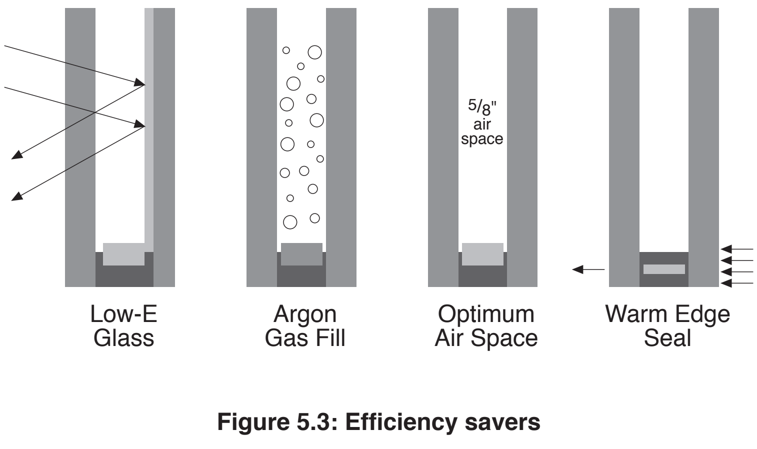


Figure 5.3: Efficiency savers

Argon gas is useful because it has a lower thermal conductivity than air. Argon is also more dense than air and that puts a damper on convection forces. Other special gases, such as Krypton and SF6 can be used or used in combination with Argon, to improve the thermal and acoustic performance of the IG units. It is important to understand that although this technology is available internationally, it is currently not offered in New Zealand.

The conventional hermetically sealed IGU uses a layer of air between two panes of glass to create the thermal barrier. This is only effective up to a point, as larger air space creates more space for convection forces to occur, which counteracts whatever benefit the added mass of air may bring. The optimum air space is around 16 mm for energy efficiency purposes, with some slight variation depending on the glass type and gas used.

If the thermal resistance of the IGU is increased (perhaps using Low E glass and/or Argon) without attention to the heat transmission occurring at the IGU edge, then the consumer does not get the best value proposition. The consumer is spending more for Low-E, but now a greater percentage of heat loss is occurring at the unit edge. In this regard, warm edge technology represents a means of capitalising upon a high performance glass package. The thermal short circuit can be eliminated by choosing an IGU edge seal system, such as Swiggle Strip (see Figure 5.1(c)), that has a low thermal conductance, thus substantially blocking the flow of heat through the edge seal system.

These products are known as High Thermal Resistant (HI-TR) Edge Seals, and independent laboratory and infrared thermograms have shown that these units demonstrate warmer interior glass surface temperatures and less heat flowing through the spacer bar and entire unit than do conventional units under thermal load conditions. Unfortunately, warm edge technology requires attention to more than just the glazing. It is also dependent upon the thermal conductivity of the frame system, and the aluminium window industry is not currently offering thermally broken window joinery. Therefore, the only thermally broken systems available are UPVC, wood or aluminium/wood composites.

The effects of air space, Low-E glass and gas filling can be seen in Attachment 1, which gives typical U-Values for a range of combinations. In general terms, the U-value of a simple air-filled IGU is half that of single glazing, i.e. $3W/m^2°C$, rather than $6W/m^2°C$. In simple terms, standard double glazing halves the heat loss from otherwise well-insulated buildings as well as providing a range of other benefits as previously discussed.

Glass, which used to be the weakest part of the thermal envelope of a building, is heading towards "Super Window Technology" that will be offering U-Values below $1W/m^2°C$ in the future. These high insulation products, coupled with advances in solar control tinting, reflective film and glass coating technology, electrically active liquid crystal film, photochromic, electrochromic and selective light transmission glasses, make the possibilities for future window technology very exciting. Further information on Super Window Technology is provided in Section 5.9.

5.4 Durability

The durability of IGUs is strongly influenced by:

- the method of manufacture, design and specification;
- workmanship during manufacture; and
- the glazing system into which the unit is fitted.

Workmanship during manufacture is important to ensure the unit design specification is met consistently. Some companies are working toward ISO 9002 quality accreditation, and some proprietary systems use in-house auditing techniques. In addition, units are tested to international testing standards, such as BS 5713, which are designed to test the seal durability of IGUs. Recently, the Insulating Glass Unit Manufacturers' Association (IGUMA) has set up a BS 5713 test facility at BRANZ to ensure its members meet the stringent requirements of this international testing procedure.

The glazing system is of paramount importance to ensure the maximum durability is obtained from a sealed unit. The main enemy of a sealed unit is water. If the seal of the unit is in contact with water for a long period, the unit will fail prematurely. Moisture can appear in a rebate area due to rain water penetration directly from the outside or through frame joints and into the glazing system, as a result of cleaning operations (internal and external), or due to condensation on the glass surface or within the framed sections. All glazing systems must, therefore, protect the edge seal of the unit, either by preventing the ingress of water into the glazing area (i.e. wet sealant systems) or by ensuring that any water that penetrates to the edge of the unit is soon removed by drainage or ventilation systems.

When failure does occur, it is usually due to desiccant saturation from moisture within the airspace. Short-term failures are normally due to poor glazing workmanship or materials, such as sealant voids or inactive desiccants. Long-term failures are usually from degradation of the edge seal from UV light or moisture created by a poor glazing system. Failures are evident when the inside surfaces of the unit condensate, and this may only happen at low temperatures. It is important to note that failures are often only visual and the thermal performance of the unit is not greatly affected.

Overseas and local experience has shown that 85% of all IGU failures are directly related to poor glazing techniques (that is the window frame detailing and method of installing the IGU), 5% of failures are related to the unit materials and 10% of failures are related to the method of manufacture or workmanship.

In a research study carried out by the American Sealed Insulating Glass Manufacturers' Association (SIGMA), only 3.2% of units tested failed after nine years in service . The most recent study of over 1000 units shows the failure rate for commercial building units over 10 years old is 1.5%. If one building complex that has a glazing system allowing direct water contact with the units is excluded, the results are 0.5%.

This study did not cover new sealant systems, i.e. Swiggle Strip, or gas-filled units, Low-E glass, capillary tubes and other new developments. The units in the field represent technology that is over ten years old.

Detailed installation instructions and recommendations are available from IGUMA or the unit manufacturer. Their instructions must be strictly followed at all times. In general, the procedures are much the same for most types of IGUs, but the methods and recommendations of the specific manufacturer should be followed. It is, therefore, important to note that unit installers who are not totally familiar with the manufacturer's glazing recommendations should not offer the product for sale.

5.5 Life Expectancy and Warranties

It is important to realise that IGUs are fundamentally different from most monolithic glass in that moisture affects the seal of the unit. However, the same is true for laminated glass and mirrors as these are also affected by moisture. Therefore, IGUs, even glazed correctly, cannot be expected to have the same life expectancy as ordinary monolithic glass. This limited life expectancy of IGUs is often not disclosed to the customer, and consequently they expect the glass to last as long as monolithic glass windows. When unit failures do occur and the customers ask the question why they were never told that the unit had a life expectancy, the industry often has no response. Such silence can give the illusion of attempting concealment of the truth, and this may be difficult to defend if any legal action ensues. In order to make a cost performance choice, the consumer has the right to know, and wants to know, what these life expectancies may be, including the cost differentials of the different types of units and what type of warranty the units come with.

Realistically, well-made IGUs that have been correctly glazed should have a life span in excess of 30 years, and some units in New Zealand already have 20 to 25 years service without any problems. However, as there are so many variables with the type of unit and manufacturer, and more importantly the glazing system, no one really knows how long the units will last in an individual application.

A good warranty is an important consideration when buying an IGU. However, there are some important considerations. Firstly, most IGU warranties are invalid if the units are glazed incorrectly, and considering this applies to nearly 85% of unit failures, the responsibility of the glazing company must be carefully considered. Secondly, a warranty is only as good as the company issuing it. Many companies have issued warranties for IGUs in the past and have not been around long enough to stand behind those warranties when the units fail. IGU warranty periods range from two to 10 years, depending on the manufacturer and/or window fabricator. Normally, the IGU warranty will outlast the window manufacturer's warranty and, often, his years as a trader. Therefore, it is important for the customer to gain the warranty from the IGU unit supplier directly. Some overseas associations demand their suppliers provide a minimum 10 year warranty, and any manufacturer who does not wish to participate in this programme will not be approved by the association.

Some overseas manufacturers have also been known to offer lifetime warranties. However, when you read the fine print, it only applies to how long you own the house; the manufacturers' rationale may be that the average family moves every five years and the warranty is then void in a short time frame.

5.6 Other Window Considerations

The principal function of windows is to let in light, provide views and form a barrier between the inside and outside of buildings. To be effective in the first two of these functions, glass needs to retain its design light transmission qualities. The second role raises issues over the structural integrity of the barriers and, particularly, occupant safety.

Easy-clean Glass

To many people, glass is synonymous with durability. Ancient glass objects have provided us with links to cultures that existed centuries ago, and the glass windows around us provide permanent barriers against the elements. Therefore, it may be surprising to many to learn that the surface of glass is susceptible to damage by rather innocuous attaching agents.

Glass surfaces attract and hold a molecular layer of moisture on the surface that in turn traps dust and dirt. Many substances bond chemically to the surface and cannot be removed by normal cleaning methods. Examples include limescale, plaster, mortar, sealants, metal oxides, dissolved silica and high alkaline-solutions, such as concrete runoff.

In addition to these hazards, the main enemy of glass is water — particularly where the attack is localised, for example, by repeated dripping or splashing. If small amounts of water regularly remain on the glass until they evaporate, a buildup of sodium ions occurs that carbonate and form a deposit on the surface. Initially, the deposit is invisible, but eventually it can form a grey and white stain that the weathering process accelerates.

Modern polymer technology has created a solution for the weathering and staining problems of glass surfaces. Advanced products such as Ritec "Clear-Shield", which basically provide a "non-stick" surface to glass similar to a frying pan, and provide a barrier between the glass and its environment, thus minimising contamination by dirt and pollutants, are becoming available. With these products, a special polymer coating chemically bonds to the surface of the glass to provide a transparent film that is non-hazardous, temperature-resistant and that won't crack, peel or discolour.

Polymer coatings are best applied to new glass, but a complete glass treatment programme that can renovate and protect existing glass onsite is available. The treatment programme also involves a range of aftercare products to ensure the surface is maintained, and as long as the surface is not subject to abrasion, the coating will last at least five years, after which it may require partial recoating.

Safer for Life

The Accident Compensation Commission (ACC) paid out $1.3 million in claims relating to glass doors and windows in the year 1989/90, and the number and cost of claims has been increasing since that time. This is despite the 1985 release of the New Zealand Standard, NZS 4223:1985, "Code of Practice for Glazing in Buildings". A survey of local bodies throughout New Zealand in August 1990 indicated that only 65% had adopted NZS 4223 as a bylaw, and casual or no enforcement occurs in 73% of those bodies that have adopted the code. Therefore, it is not surprising, perhaps, that New Zealand has an injury rate of 15 per 100,000, which is higher than is reported in other countries, and there have been nine fatalities recorded between 1977 and 1986, eight of which were in the home.

A home owner survey (Dialogue Consultants, 1992) indicated that: "Glass is a featureless commodity to which most people pay scant attention". This lack of awareness, coupled with the accident statistics, led to the formation of the New Zealand Safety Glass Association (NZSGA). The NZSGA has been active with their

"Safer-for-Life" campaign, which involves a decision-tree poster to help determine the appropriate type of glass, as outlined in NZS 4223. This has been circulated to designers, building inspectors and the general trade. A brochure has also been produced for the public with ACC sponsorship, along with several press releases to explain the type and applications of safety glass.

The NZSGA has also been active behind the scenes with submissions to the Building Industry Commission on the proposed New Zealand Building Code and a submission to the Minister of Consumer Affairs to outlaw annealed glass in shower screens. It has also worked closely with BRANZ on recent bulletins and a test programme for evaluating annealed glass strengths. In addition, it has prepared a draft revision to NZS4223 for the Standards Association of New Zealand (SANZ), which was released for industry comment and subsequently issued as NZS4223 Part III Human Impact Considerations.

The NZSGA has also introduced a label system for its members to apply to cut laminated safety glass to help the building inspectors identify safety glass and has instigated a "Bandaid" awareness campaign with councils and building inspectors. It also gives seminars to building inspectors and clerk of works conferences, and many other promotional activities are planned.

The NZSGA would like to assist designers in any way it can and would like designers to take a responsible attitude to specifying and policing glass installations in both domestic and commercial buildings (NZSGA, Box 14-601, Panmure, Auckland).

5.7 Alternatives to IGUs

Retrofitting IGUs to existing windows can be very difficult. Using well-fitted, heavily pleated curtains with a pelmet can provide almost the same insulation as double glazing, but the use of curtains requires active householder management. Alternative passive approaches are available that provide almost the same performance as double glazing.

Effective Curtains

Many people are not aware of the two principle requirements for effective conventional curtains. Firstly, when drawn they should seal the edges of the window frame. Curtains tracks are often placed so that the curtains stand out from the frame when drawn. This problem can be compensated by having deep folds in the curtains when drawn so that several folds rest against the wall beside the window frame. With modern, slim aluminium joinery with condensation drains, it may be possible to place the track and curtains inside the reveals and obtain a good all round seal. Sealing the top of the curtain with pelmet is highly desirable to reduce heat losses. Less important, but useful, is to be able to seal the bottom of curtains by such means as having the drop just sit on the floor.

The second important factor with curtains is their weight. Contrary to popular opinion, there is no evidence that so called thermal drapes provide any additional benefit (*Consumer* No. 315, 1993). All things being equal, thick curtains provide better insulation than thin ones. Double-glazed windows with no curtains will lose a similar amount of heat as a single-glazed window that has well-fitted curtains drawn. Obviously, a double-glazed window with curtains is the best approach. If a house has single-glazed windows and retrofitting double glazing or an acrylic sheet (see below) is not possible, then using good curtains effectively is essential.

New curtaining materials and systems are coming onto the market and householder and interior decorators/ architects should be aware of their energy efficiency possibilities while maintaining a healthy scepticism for manufacturer's claims. For example, one new concertina curtain system has a cross section made up of thin-walled closed and joined hexagons when drawn. Carefully placed between modern reveals, this could simulate a very heavy curtain.

Acrylic Sheet Retrofits

It is possible to place a sheet of acrylic polycarbonate over the inside window frame or within the reveals to create an air gap. The main issues are creating a good seal around the edges and using a fixing method that allows easy removal of the sheet for window cleaning or to provide ventilation.

One New Zealand company has recently obtained a license to franchise an overseas system that deals with these problems. The Magnetite Inside Insulating Window system (BRANZ, 1994) consists of an optically clear 2.5 mm or 3 mm thick acrylic sheet contained within a white or brown alloy frame, which incorporates a barium ferrite magnetised gasket. A timber bead is attached to the inside of the window reveal and a galvanised and painted metal strip is attached to the bead. The acrylic panels have lifting lugs that allow them to be easily placed and removed from the window frames.

Satisfactory thermal performance is obtained if the acrylic sheet is placed between 25 mm and 75 mm from the existing window glass (window fittings may limit how close the sheet can be placed). The seal should be sufficiently tight to ensure that warm, moist internal air does not get into the cavity and condense on the glass. As well as providing an air gap, such systems also prevent draughts through gaps around the window sashes.

Glass Block Systems

Glass blocks are playing an ever-increasing role in the fashion, form and function of modern architecture. They are not strictly an alternative to an IGU, as they will be specified for reasons beyond energy and noise considerations. Glass blocks are a very useful building component because they:

- control light;
- conserve energy;
- reduce noise;
- improve comfort;
- increase security;
- provide privacy;
- reduce maintenance; and
- provide fire protection.

Glass blocks are available in a wide range of sizes and patterns, clear or coloured in bronze, blue, green, pink or grey. They can be made to diffuse light, direct light, reflect light and heat (and can even be made bullet-resistant). In addition, a range of hollow or solid pavers are available for walkways, floors and roof lights. Special blocks for constructing corners, angles and ends of walls are also available.

There have been important advances in glass block technology in recent years. Joints are now smaller, which allows better light transmission, and they are more aesthetically appealing. The joints are not conventional mortar, but a more water-resistant silicone sealant is used that also provides better insulation. The perimeter frame is anodised or powder-coated aluminium that is not only attractive, but also provides simplicity in design, installation and alteration.

Not visible are the internal plastic clips and the reinforcing bar system that separates the blocks and locates them within the perimeter frame. The system is fast and easy to install, is resilient under impact and flexible in earthquakes.

A revolution in glass block installation has started with such proprietary glass block systems as the “Steck-fix” system becoming available. The Steck-fix system has been designed and tested in Germany, and tested and approved in New Zealand by BRANZ. Testing included wind load pressures of 4 kPa, earthquake racking equivalent to 5% inter-storey drifts and pendulum impact loads to simulate human impact.

Designers can now specify a glass block system that overcomes the pitfalls that have plagued conventional mortar glass block wall construction and gain additional benefits as well.

5.8 Market Barriers

Education

The market is largely unaware of the benefits of double glazing as a form of insulation for energy efficiency and conservation. This problem is difficult to address because most of the potential IGU users are not in direct contact with IGU manufacturing companies. The majority of the IGUs are distributed through the aluminium window industry, and this industry has a reluctance to promote products such as double glazing, which increases costs, to their customers. The other problem is that the market is not big enough to justify mass media expenditure, and this is the only other real way to increase awareness other than through legislation or promotions with EECA or similar organisations.

Window Industry

Approximately 90% of new domestic dwellings have aluminium windows and the IGU manufacturers are thus, to some degree, reliant upon the aluminium window industry to promote their products. Generally, any promotion is aimed at the builder and not the home owner directly. In addition, the window industry is not totally competent in IGU installation, and because of problems with failures in the past, they do not promote them and/or price them out of the market so as to avoid their use. This problem has been addressed by the formation of the Insulating Glass Unit Manufacturers' Association (IGUMA), which is a trade association within the Architectural Aluminium Association (AAA). As mentioned in Section 5.4, the IGUMA has set up testing facilities with BRANZ to ensure that unit quality is controlled. It has also prepared a series of fact sheets on the use and installation of IGUs which have been circulated to the aluminium window industry.

Incompatible Window Systems

Many of the early window systems were not suitable for IGU installation. This relates not only to aluminium, but also to timber joinery. Most of the new PVC window systems have been designed in Europe and are designed for IGU installation, but they are a small percentage of the market. Over the last few years, considerable work has been done by the aluminium window industry in improving their window systems. To date they have not offered thermally broken windows systems to the market, but there are signs that these will be available in the near future.

Standard Windows

Unfortunately, the New Zealand building industry has been spoiled with the ability of small window manufacturers to make windows of any size and shape. The industry does not have standard window sizes and therefore no repetitive volume to gain manufacturing efficiencies and price economy. The introduction of standard window sizes will require an extensive education programme for the builders who are used to leaving "holes in walls" and asking the window industry to fill them with windows made to measure. Similarly, architects may need to design around standard sizes rather than having a completely free hand.

IGU Manufacturers

The total domestic IGU market is estimated to be 62,000 m^2. Currently, the IGUMA have 10 members, with an additional five or more smaller manufacturers throughout New Zealand. With the volume of the market spread between these 15 manufacturers, the plants cannot obtain high manufacturing efficiency that would lead to the lowering of unit costs. It is estimated that the volume would have to increase by 100% to decrease costs by 20%, as the cost of raw materials does not alter significantly, only the labour content and overheads.

5.9 Window Thermal Performance in the Future

Technology

Glass used to be the weakest part of a window, but it has now advanced to a point that U-values of 1.8 W/m^2K can be obtained with combinations of Low-E and reflective glass, and even "super-window" technology is looking at U-values below 1.0 W/m^2K. Therefore, the frame systems are playing catch-up as the industry moves to create the perfect thermally efficient window.

Glass manufacturers are working towards better solar control properties with their tinted glass compositions, and PPG (Pittsburgh Plate Glass) "Azurlite and Graylite" and LOF (Libbey Owens Ford) "Evergreen" are good examples of these. These glasses combine low shading coefficients with high visible light transmission, and excellent properties result when advanced coating technology is combined with these new substrates. In addition, glass manufacturers are also making "clearer" and/or white glass such as PPG "Starphire" and AFG Industries "Krystal Clear" for interior design (e.g. furniture and mirrors).

There are a number of superwindow technologies currently being developed in the US and Europe:

- Electrochromic glazing, where a small voltage is applied to a special glazing, which changes the glass from clear to opaque greatly reducing heat gain or night radiation loss.
- Glazing integrated with transparent solar cells that generate electricity (ideally by absorbing UV) yet still let daylight in.
- Creation of a vacuum between sheets of glass to virtually eliminate heat convection, or the insertion of Aerogel between glazing panes (aerogel is a low mass transparent material with exceptional insulation properties).
- Use of holographic coatings to redirect light to gain better penetration into rooms or to target sunlight at passive solar heat storage.

Switchable glass, or "Smartglass", is already available in the form of Talig "Varlite", which uses an electrically activated liquid-crystal film to change the glass from clear to opaque. A lot of research is going into a true electrochromatic glass that has a coating that when electrically charged darkens the glass and controls both light and solar heat gain. This type of glazing could be connected to the building's lighting and air conditioning system and thus respond to the environment. Photochromatic glass reacts to light changes and this technology is available to opticians but not yet for commercial applications.

Holographic coatings can also be applied to a window's upper portion to assist with interior lighting. These prismatic materials can redirect sunlight that would otherwise strike the floor up toward the ceiling. The ceiling would reflect the light onto workspaces or deeper into the room, achieving the same standard of lighting levels as electric luminaires.

Public and Corporate Policy

Thermal performance of windows will be of key importance in the 1990s as governments, worldwide, work towards making their countries more energy efficient. The industry's task is to help consumers choose more energy efficient building products, both in new construction as well as in renovation projects. In this regard, the United States government has recently taken the lead by passing legislation mandating the fenestration industry to establish standards for rating and labelling of window thermal performance properties. This gave rise to the National Fenestration Rating Council (NFRC), whose mission is to create a fair, accurate and creditable rating system and to coordinate certification and labelling activities to ensure a uniform application of the system.

In the USA, many states are introducing or are developing state energy codes to enforce the introduction of energy conserving products. In some areas, utility companies are sponsoring rebates to builders and new home purchasers to install energy saving products in new construction projects. Home Energy Rating programmes (like HERO in New Zealand), coupled with support from participating financial institutions, are encouraging energy saving renovations of existing homes prior to change of ownership. The introduction of these projects, in addition to other education programmes sponsored by utility companies and various conservation groups, is resulting in a marketing environment in which consumers are more informed than ever before with respect to the benefits of choosing energy saving window products.

New Zealand manufacturers have shown a degree of self regulation with the formation of the IGUMA. Organisations such as EECA need to do more to promote the benefits of IGUs until the market responds enough for manufacturers to cover marketing overheads. Window systems manufacturers need to be able to supply double-glazed window units incorporating the latest proven technologies, and all parties should start to recognise the benefits of a degree of window size standardisation. Finally, there is a role for the pending new thermal performance component of the building code to require that attention be paid to the fenestration as well as wall, floor and ceiling insulation. The Australian GMI (Glazing-Mass-Insulation) scheme mentioned in Chapter 3 is pertinent in this regard.

References

Building Research Association of New Zealand, *BRANZ Bulletin 292 — External Insulation and Finish Systems*.

Building Research Association of New Zealand, (1994). "Magnetite inside insulating window system", *Appraisal Certificate No. 280*, 1994.

Consumers Institute (1993). "Questions you ask most often: thermal drapes", *Consumer*, No. 315, May 1993.

Dialogue Consultants (1992). *Safety Glass Promotion: Communications Analysis: Final Report*, prepared for the New Zealand Safety Glass Association.

NZS4223:1985. "Code of practice for glazing".

Attachment 1: Performance of Different Glass Combinations

The tables and figures below show the performance of different combinations of glass, glass thickness, airgap, etc. The first set of figures in the identifying code refer to the type and thickness of the outer glass. The second set refers to the air gap and its width (mm) and whether it has argon instead of air. The third set of figures relate to the inner glass. The performance of a triple glazing unit (3/12/3/12/3) is also presented.

The performance is expressed in terms of U-value. A U-Value is the thermal transmittance of a material. It evaluates the amount of heat (watts) that passes from one side of the glazing to the other side for every square metre of glazing area and degree C in temperature difference. The lower the U-Value, the better the insulation.

Glass/Unit Type	**U Value W/m^2°C**
Single 3 mm	6.31
3/12/3	2.79
3/12A/3	2.62
3/12/3LE	1.99
3LE/12/3LE	1.83
3LE/12A/3LE	1.53
3/12/3/12/3	1.79

Glass/Unit Type	**U Value W/m^2°C**
Single 6 mm	6.12
6/6/6	3.22
6/12/6	2.74
6/12A/6	2.58
6/12/6LE	1.95
6LE/12/6LE	1.80
6R/12/6	1.76
6R/12/6LE	1.71
6/12A/6LE	1.69
6LE/12A/6LE	1.51

Note: Calculated from the “Windows 4” computer program

LE = Low E glass.

R = Reflective glass with sputter coating

A = Argon gas

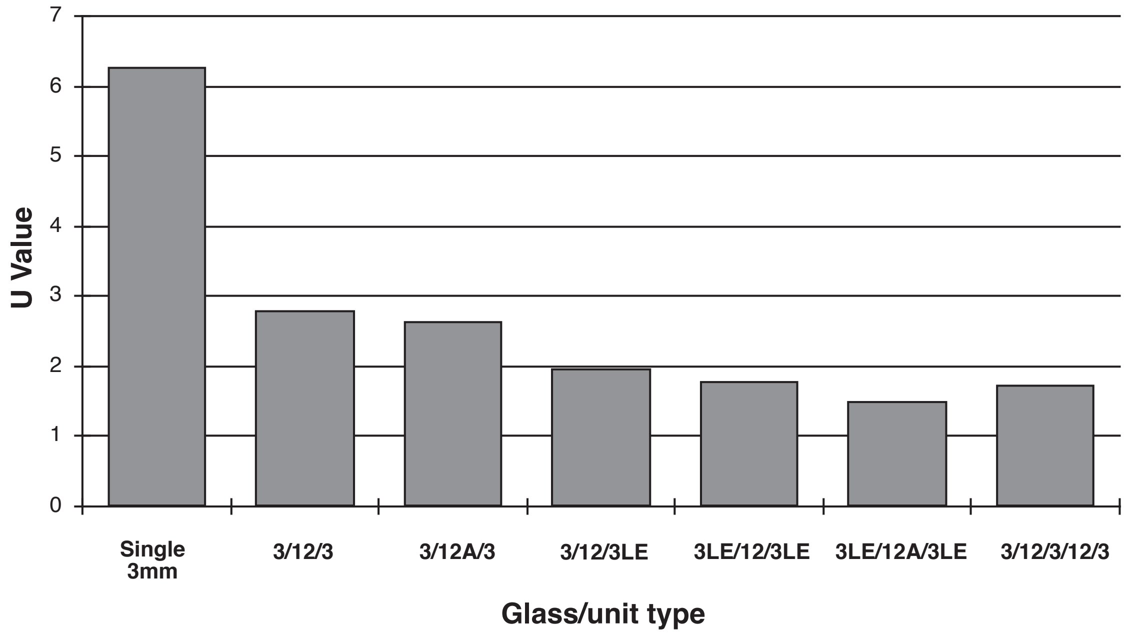


Figure 5.4: Glass insulation — 3 mm glass combinations

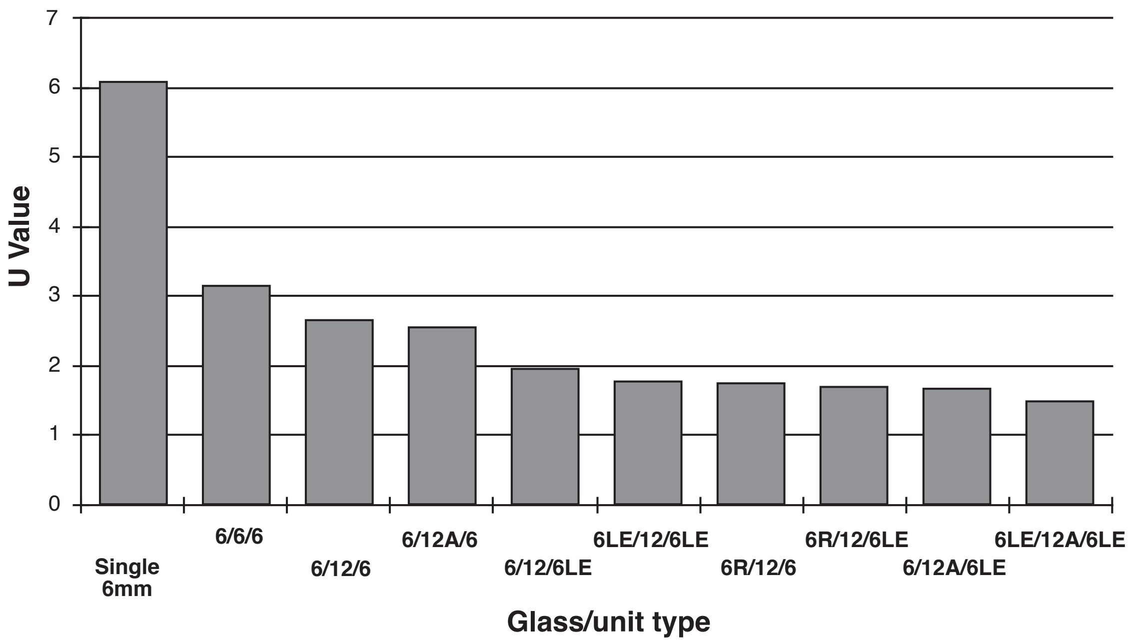


Figure 5.5: Glass insulation — 6 mm glass combinations

Attachment 2: Low-E High-T

Low-Emissivity glass, or Low-E glass as it is more commonly called, has been commercially available since 1990. It evolved from the magnetic sputtering technology that was developed to coat glass with thin, metallic, reflective surfaces for solar control purposes.

There are two types of Low-E glass: the original sputtered coatings, and the more recent pyrolitic Low-E glasses, which are produced by coating the glass on-line as part of the primary manufacturing process of float glass. These new on-line coatings are often called "hard-coated" glasses as the coatings are extremely durable, making them easier to handle and process than the off-line "soft-coated" sputtered coatings. Low-E glass is simply ordinary float glass with a special transparent coating on one surface that reflects heat, (long wave infrared radiation) and keeps much of it from passing through the glass.

Low-E glass was originally used to improve the thermal performance of double-glazed windows to that of triple glazing in cold climates that have high insulation regulations. The Low-E coating transmits solar energy from the sun, which warms objects in the room. These objects, along with the heating system, radiate long wave infrared energy which tries to pass through the glazing but is reflected back into the room by the Low-E coating.

For cold climates, the Low-E coating is normally used on the third surface (airspace surface of inner pane) of an Insulating Glass Unit (IGU). This creates a warmer inner glass temperature in the unit, which improves comfort and further reduces the onset of condensation. In addition, the Low-E coatings also reduce the transmission of UV light, which reduces fading and degradation of furnishings. This Low-E window technology has revitalised the window and door industry in Europe and the US to such a degree that many window companies offer it as standard.

For hotter climates, the outer glass of the IGU can be a tinted or reflective solar control glass can be used to reduce the solar heat gain in the building. This combination of high thermal insulation and excellent solar control properties provide the basis for high tech (High-T) windows of the future.

The most recent advances in High-T windows for hot and tropical climates is to apply the Low-E coating to the second surface (airspace side of outer glass) on a tinted exterior glass in an IGU. This type of window is often called "Sunbelt Low-E" and works by re-radiating outward the solar energy absorbed by the tinted glass. The result is the airspace is kept cooler as conductive heat gain is substantially reduced, providing low shading coefficients, so much so that glass manufacturers now provide a range of Low-E coatings for such applications. To further enhance the thermal performance of IGUs, manufacturers are using gas filling techniques and high thermal resistance spacers, such as "Swiggle Strip", in combination with Low-E glass.

Unfortunately, window frame manufacturers are being left behind as their frames are too conductive and affect the overall thermal performance of the window systems. Therefore, a lot of research is going into framing materials and systems as the world's energy-conscious markets move towards window energy rating systems. The thrust of this international research concentrates on composite design, using the attributes of several different materials, i.e. wood, vinyl and aluminium.

Chapter 6
Ventilation in Homes: A Crucial Issue

6.1 Introduction

Homes need adequate ventilation and the means to achieve this are covered in this chapter. Ventilation means heat loss from the house on cold days, which makes home energy efficiency measures such as solar heating and insulation doubly important. Furthermore, as the information in this chapter shows, good ventilation can be a direct energy efficiency strategy. The alternative to ventilation for moisture control is either extra heating or use of dehumidifiers. The most energy efficient strategy will be the right mix of ventilation, heat and direct moisture control.

Ventilation is both an energy efficiency issue and an indoor air quality issue. Moving fresh air into a house often means a loss of heated indoor air, but effective ventilation is essential. This means that any new approach to ventilating homes in New Zealand will have to consider issues of health and moisture control, as well as returns from the efficient use of energy.

Background air infiltration provides a useful level of ventilation in most existing houses, but the trend in new houses is towards more airtight construction and, therefore, more reliance on window opening. The problem with this is that open windows are insecure and not easily adjusted to provide ideal background levels of ventilation. This trend is more as a result of changing materials and construction practices than a consequence of home energy efficiency improvements or ventilation performance targets in the national building code. It has led to air infiltration alone not providing the necessary background ventilation that was present in older homes, and has created a need for a way of adding ventilation that is consistent with home security, weather tightness and draught control.

The energy implication of 0.5 air changes per hour (ac/h) of ventilation in houses insulated to current requirements is significant. It represents about 20% of the total envelope heat losses, but higher ventilation rates or moves to higher levels of insulation would increase this proportion. In the most extreme climates in other countries, mechanical ventilation systems are used to supply ventilation on the basis of occupancy or demand. This approach can be energy efficient where there is recovery of heat from exhaust air, but it does require houses to be constructed to a high level of airtightness. In less severe climates, passive ventilation strategies are used to provide background levels of ventilation. These strategies will often be combined with mechanical ventilators in bathrooms and range hoods to effectively remove moisture at the source.

The temperate climate in New Zealand is likely to mean that passive ventilation will be favoured for the foreseeable future. There are some scenarios that could bring about wider use of mechanical systems. The most likely of these would stem from the need to control indoor moisture levels so that dust mites (a particular problem for asthma sufferers) and mildew are not supported. In this scenario, mechanical heat recovery ventilation could have a role in houses, along with thermal insulation and the removal of damp air at source.

6.2 Requirements for Ventilation

One result of insufficient ventilation can be the formation of condensation and the growth of mildew on walls. Trethowen (1971) found this to be a common problem in New Zealand houses. A significant fraction of houses (45%) had some form of moisture problem, with mildew in wardrobes (25%), mildew on bedroom walls (20%) and mildew on other walls (11%) being the three most common problems. Such problems were more common in the northern towns, which was thought to be a result of lower use of space heating reducing the moisture-carrying capacity of ventilation air. The factors involved in moisture control are:

- moisture emission rates (typically 5 to 10 kg/day in an occupied house (but potentially larger);
- the heat input into the building (solar heat gains, space heating, etc.);
- the ventilation rate;
- the thermal insulation of the building shell, floor, walls and ceilings; and
- the moisture storage capacity of building materials and furnishings.

The role these factors play in moisture control in houses has been reviewed by Trethowen (1987) and Bishop (1987). Figure 6.1, from Bishop (1987), illustrates the interaction between heat input, ventilation and the level of insulation. The figure shows condensation threshold curves for a single glazed window and an insulated wall. The condensation threshold is the point at which condensation begins to form. For a point defined by a ventilation rate and an indoor heat input value that lies to the left of the curve, condensation will form, and to the right it will dry out.

Most houses built since 1977 have been insulated to NZS 4218P:1977 “Minimum thermal insulation requirements for residential buildings”. This will have helped reduce indoor moisture problems by increasing the average temperature of indoor air and of wall surfaces. At present, there are no survey results directly comparable with the earlier survey of moisture problems (Trethowen 1971), but there are indications that dampness problems persist.

6.3 Health Implications of Indoor Moisture

Links between poor health and indoor moisture levels have been suspected for many years but have been difficult to establish. A recent survey by Kearns et. al. (1991) of health and housing difficulties of people living in Auckland and Christchurch has found some association between health problems (including running noses, colds, rheumatism, headaches and asthma symptoms), damp and cold. Interestingly, a greater proportion of damp and cold problems were reported in Auckland, with a closer analysis of the data showing socioeconomic status to be a factor (leading to an inability to afford heating).

Similar surveys have been carried out in other countries. Platt et. al. (1989) surveyed dampness and health in 597 houses in the UK and found that adults living in damp homes were more likely to experience blocked noses, breathlessness, backache, aching joints, fainting and bad nerves than those living in dry dwellings. Those living in mouldy dwellings were also more likely to report a wide range of health problems. The differences remained even after accounting for socioeconomic status and cigarette smoking. For children, living in damp dwellings was associated with a greater occurrence of wheezing, sore throats, runny noses, coughing, headaches, and fever, and with the exception of coughing, these differences were unaffected by the introduction of controls for smoking in the household, employment and overcrowding.

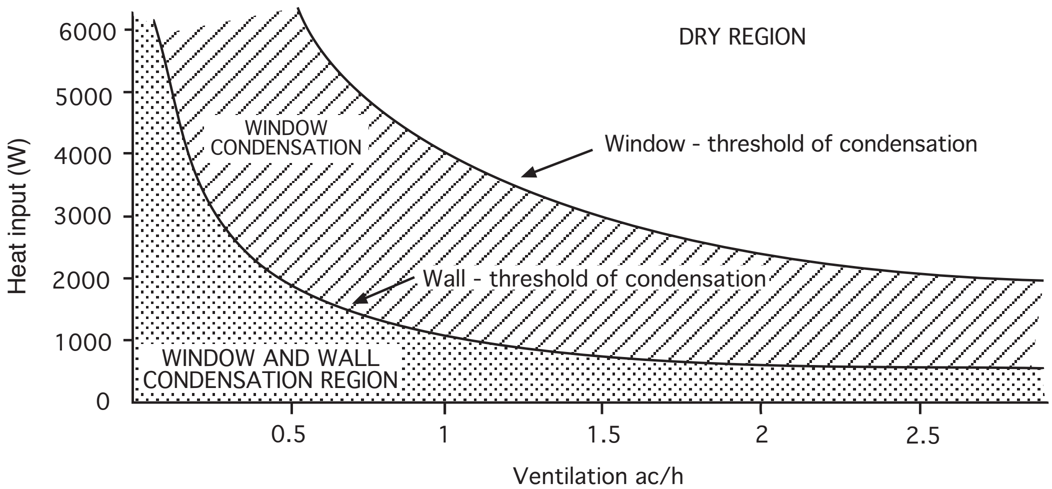


Figure 6.1: Condensation threshold curves for an insulated wall and a single glass window

Studies are underway in New Zealand into the potential link between indoor temperature and humidity, dust mite levels and health factors. Other health concerns that might be addressed by good ventilation relate to indoor pollution from gases given off by building materials and finishing materials (e.g. formaldehyde).

6.4 Ventilation Practices

Homes in New Zealand are most commonly ventilated by opening windows. Open windows give user-regulated fresh air, but the following factors work against their use for all ventilation needs:

- security concerns sometimes lead to closed windows while the building is occupied and almost always when unoccupied;
- closing the windows reduces the transmission of sound from outside; and
- accurately regulated ventilation is difficult to achieve without draughts.

Window opening habits have not been surveyed in New Zealand, but are highly variable. There is, however, another source of ventilation and that is air infiltration. This consists of air that leaks through defects in the building shell. Air infiltration has been shown by Bassett (1986a) to provide an adequate background level of ventilation in older homes, and therefore the practice of opening windows may have rarely been necessary for critical contaminant control. Air tightness of New Zealand homes has, however, changed steadily (Bassett, 1986b). Houses of more recent construction are more airtight than older houses, mainly because sheet interior linings that eliminate joints between materials and more accurately-gauged materials and fittings have become more widely used.

Natural air infiltration will still provide useful ventilation (particularly for larger, more complex designs), but simple designs (often low cost housing), should be investigated for ways of adding a further secure and reliable background ventilation into these homes. This could take the form of passive vents or mechanised ventilation. The airtightness of houses in a range of countries is shown in Figure 6.2. Houses constructed in New Zealand are not much different from houses constructed in countries of similar climate.

The histogram of house airtightness data can be transformed into air infiltration rates at atmospheric pressures using assumptions about the climate and the degree to which the house is exposed to wind. The approximate range of average winter air infiltration rates for houses in the Wellington region is given in Figure 6.3. The mean infiltration rate lies quite close to 0.5 ac/h, indicating that many houses have average winter infiltration rates in the desirable 0.5-1.0 ac/h range without the building industry having to work to airtightness targets. However, about 20% of new houses (those with air infiltration rates less than 0.4 to 0.5 ac/h) would benefit from added background ventilation. If it is to be argued that a basic level of ventilation (say 0.5 ac/h) should somehow be built into houses during construction so that indoor air quality needs are met irrespective of user-controlled ventilation, then air infiltration (or a substitute for it) should be carefully examined.

6.5 Trends in Codes and Standards

Ventilation provisions in new homes in New Zealand are regulated by the Approved Document G4 in the National Building Code (Building Industry Authority, 1992). For naturally ventilated homes, the level of performance required is "... an adequate number of air changes to maintain air purity". One acceptable solution to achieve this (G4/AS1) calls for opening window areas of at least 5% of the floor area in each room. The problem with this is that the need for home security while people are away at work or asleep at night, and the need for acoustic isolation in houses more densely packed in new subdivisions are inconsistent with open windows.

Outside the building code, there are various standards and recommendations that deal with indoor air contamination. NZS4303:1990 "Ventilation for Indoor Air Quality" is a New Zealand adaptation of the United States ASHRAE standard 62-1989 of the same name. For residential buildings, it gives minimum ventilation rates for different rooms that are approximately equivalent to a house average ventilation rate of 0.5 ac/h. This is typical, internationally, of domestic building ventilation standards at the present time.

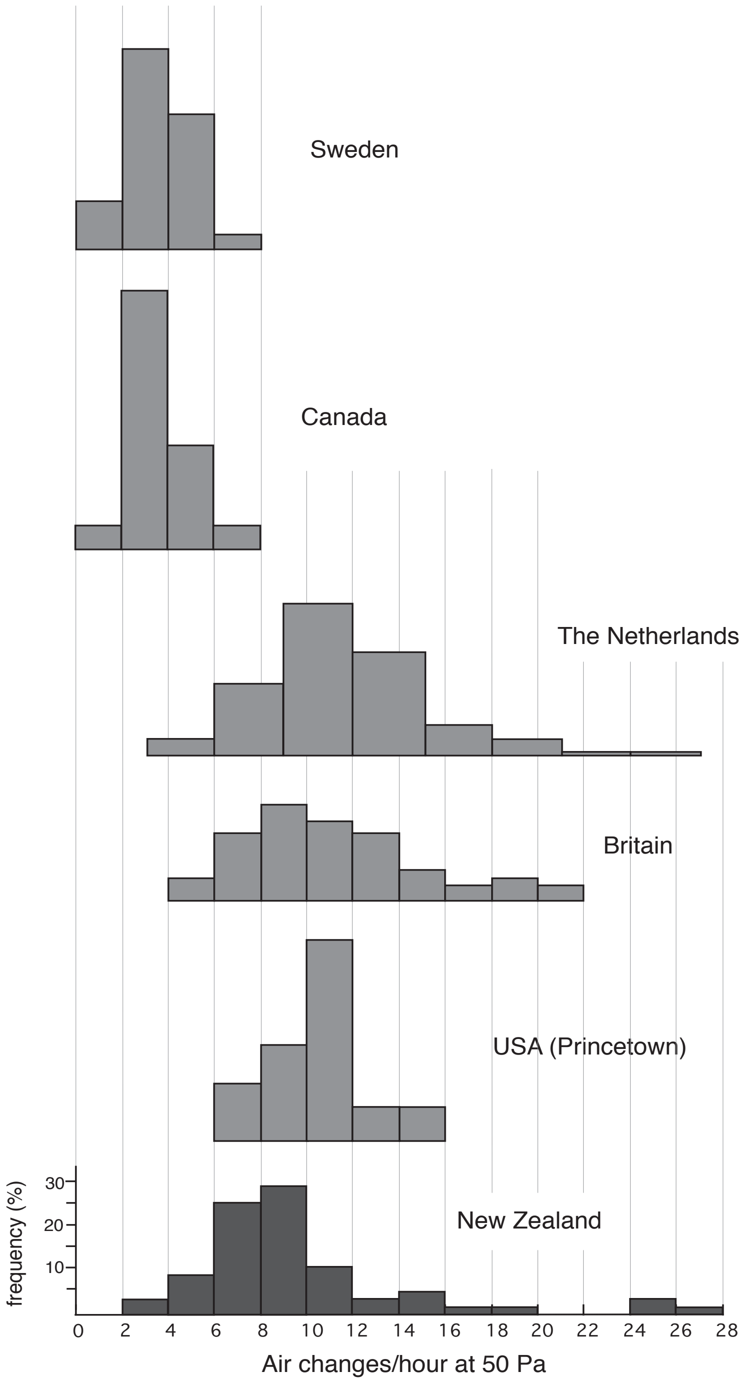


Figure 6.2: Relative airtightness of houses measured at 50 Pa

The Department of Health (1988) has published time-weighted concentrations for a range of contaminants in the work place in "Workplace exposure standards for New Zealand". For non-industrial buildings such as schools and homes, contaminant concentrations of concern are less well defined, and where no particular standard exists it has become common practice to adopt 1/10 TLV (Threshold Limit Value). Perhaps the most respected data is the World Health Organisation list of contaminant concentrations of concern reproduced as Table C-4 in NZS 4303:1990. This provides action levels beyond which both ventilation and the source of contamination should be investigated.

Early in 1990, formaldehyde was found to be causing health problems in a number of houses. In these cases, the WHO action level of 0.1 ppm was used to trigger further investigation of ventilation and formaldehyde source strengths.

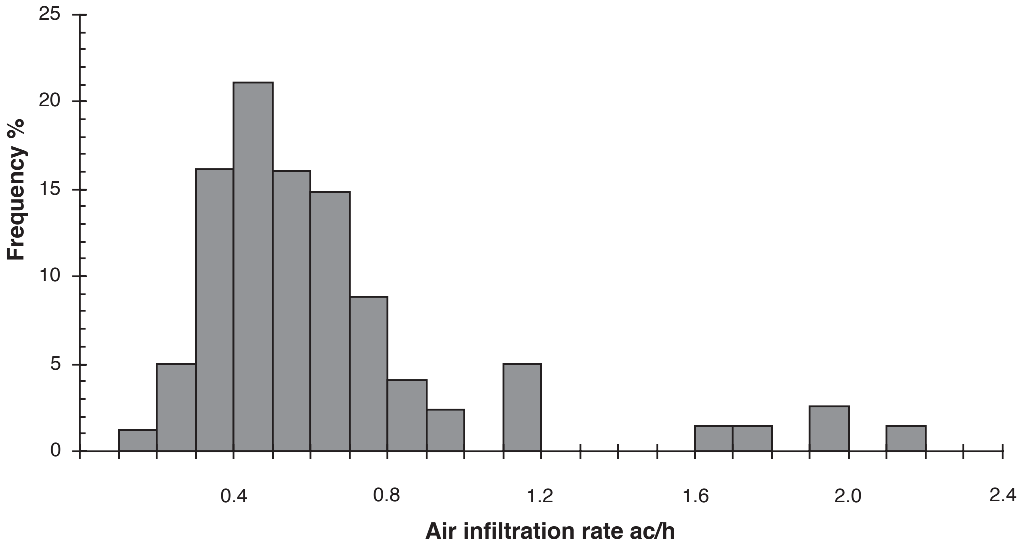


Figure 6.3: Mean winter infiltration rates for buildings of all airtightness levels located in the Wellington climate

6.6 Ventilation Options suited to Temperate Climates

The ventilation practices most likely to be applied in New Zealand are those that are cost effective, in keeping with heating and ventilating buildings in temperate climates where moisture control is an issue. Passive options and mechanical systems employing heat recovery demand-type controls are discussed below. A partial alternative to improved ventilation, the use of dehumidifiers, is also discussed.

Passive Ventilation

The advantage of passive ventilation is that the ventilators are inexpensive to build into new houses. They are also consistent with home security and weathertightness, but have a down side in that the ventilation rate will be determined by climatic factors and, therefore, be quite variable. There are advanced passive ventilators available in some countries that close under high wind pressures. In practice, most people would not notice too little or too much air supply because of the large reservoir that the enclosed air represents.

One range of aluminium windows now available in New Zealand comes with a built-in adjustable vent between the bottom of the glass and the sill. Using this system allows the ventilation of a window with no loss of security and minimal sound transmission.

Passive ventilation practices are specified in the building codes of a number of countries with climates similar to New Zealand. The approved document F1 of the British Building Regulations is one example that allows a trickle ventilator with an open area of 4000 mm^2 for rooms having an exterior wall, provided it is controllable and located to avoid draughts. Kitchens require a mechanical extractor capable of 60 *l*/s for rapid ventilation, but a 4000 mm^2 trickle vent or a low speed mechanical system delivering 1.0 ac/h are sufficient for background ventilation. Bathrooms require 15 *l*/s of intermittent mechanical extraction.

Mechanical Ventilation

The colder Scandinavian countries tend to favour mechanical ventilation because it offers tighter control over fresh air delivery and can easily incorporate heat recovery. Envelope airtightness control will almost always be required to ensure that the mechanical ventilator has control over most of the fresh air needs. In Sweden, detached single family houses have to achieve better than 3 ac/h at 50 Pa. In New Zealand, the ECNZ Medallion 2000 houses fitted with heat recovery ventilation have to achieve better than 7 ac/h at 50 Pa. The range of active ventilator configurations is too great to describe in detail here, but further information can be gathered from Air Infiltration and Ventilation Centre Technical Note 35. The opportunities available with mechanical ventilation are:

- fresh air delivery can be tightly regulated to standard requirements and can be independent of the climatic driving forces of air infiltration;
- there is an option to vary fresh air delivery rates to control changing pollutant concentrations, such as carbon dioxide or water vapour;
- extract points can be located to remove pollutants from sources in kitchens and bathrooms; and
- heat can be recovered from exhaust air and passed to incoming fresh air;

Disadvantages of mechanical systems include:

- added cost and complexity to houses;
- adequate ventilation will depend on the design, installation, commissioning and ongoing maintenance of the ventilator hardware, all of which must be satisfactory for effective contaminant control in airtight houses; and
- the need for envelope airtightness control.

Dehumidifiers

The use of dehumidifiers is being strongly marketed in New Zealand. Dehumidifiers are a combination of heat pump and fan. Moist air is blown through the evaporator, which causes water to condense. This then flows to holding tank or out a permanent drain. The principles of heat pump dehumidification are described in Volume 2 (for example, see Section 5.3 of Part 4 “Primary Production”). Under cold air conditions, icing of the evaporator unit could occur, but most models have various means to avoid this or remove ice (e.g. reversing the refrigeration cycle). The overall energy efficiency of available models varies. Some are designed to pass the latent heat obtained from the condensed moisture back to the air stream, and thus counter the air cooling effect (see Figure 6.4). This reduces the need to use direct space heating to maintain room temperatures.

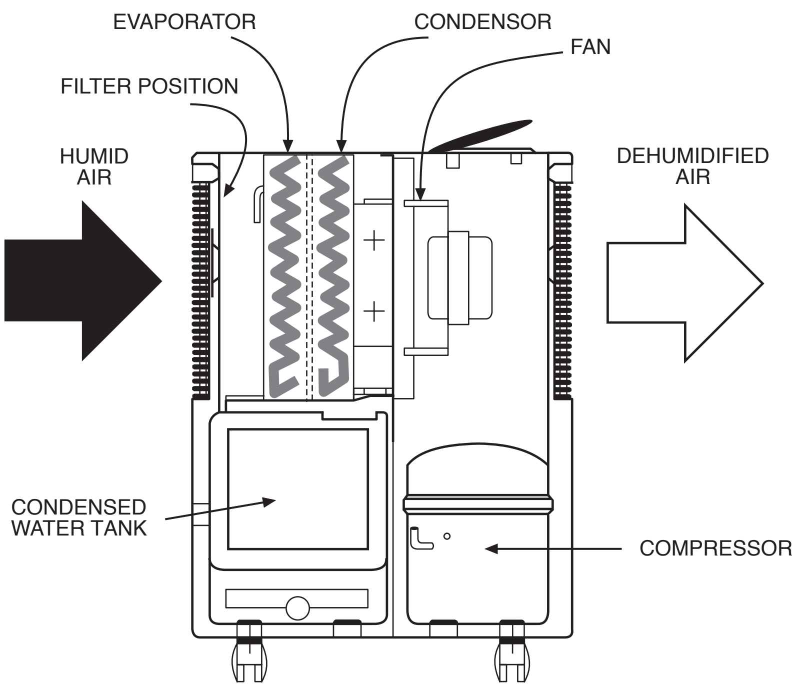


Figure 6.4: Dehumidifier schematic

Some models have air filters that can remove dust and lint, but otherwise dehumidifiers only address moisture issues rather than the other dimensions of air quality, such as contaminant levels. Dehumidifiers were the subject of a consumer review in 1992 (*Consumer*, 1992). At 20˚C and 90% relative humidity, model performance varied from 5 to 8 litres of water removed per day. At 10˚C and 70% relative humidity, the removal rates varied from zero to 4 litres per day (better performing units became available in 1995). These removal rates need to be compared with typical moisture generation rates.

Typically from 5 to 15 litres per day of moisture is generated inside a house from respiration (1 litre per person), cooking (3 litres), bathrooms (2 litres per day), unvented clothes drying (5 litres) and unflued LPG and gas heaters. Furthermore, some homes have a problem with high underfloor moisture levels from groundwater or other sources of moisture penetration into the home. Unless a good effort is made to reduce moisture generation at source and vent moisture by using windows and fans, dehumidifiers will struggle to adequately dry the indoor air. At costs of $500 to $800 per unit, there are less expensive options, such as installing automatic bathroom extractor fans direct venting to outside air.

Increased ventilation can cause loss of warmed space air. Consequently there may be a role for dehumidifiers to favourably alter the balance between ventilation and space heating input to avoid condensation (Figure 6.1). Most dehumidifiers require 500 to 600 watts of power. A useful piece of research would examine whether their use lowers the window and wall condensation threshold curves shown in Figure 6.1 by more than their power demand. A minimum air exchange level (possibly around 1.0 air changes per hour) needs to be maintained to keep contaminant levels down.

References

Air Infiltration and Ventilation Centre (1992). *Advanced Ventilation Systems — State of the Art Trends*, Technical Note 35, Coventry.

Bassett, M R (1986a). *Building Site Measurements for Predicting Air Infiltration Rates. ASTM Symposium on Measured Air Leakage Performance of Buildings*, STP 904, pp. 365-383, Philadelphia.

Bassett, M R (1986b). *The Infiltration Component of Ventilation in New Zealand Houses*, Air Infiltration and Ventilation Centre, Proceedings of the 6th AIC Conference, Het Meerdal Park, The Netherlands.

Bishop, R C (1987). *Ventilation to Reduce Indoor Condensation,* Air Infiltration and Ventilation Centre Workshop on Moisture, Wellington.

Building Industry Authority (1992). *New Zealand Building Code, Approved Document G4, Ventilation*, Wellington.

Consumers Institute (1992). “Test — dehumidifiers”, *Consumer* No. 303, April 1992.

Department of the Environment (1990). *The British Building Regulations, Approved Document F1, Means of Ventilation*, London.

Department of Health (1988). *Workplace exposure standards for New Zealand* , Wellington.

Kearns, R A, C J Smith and M W Abbott (1991). “Another day in paradise? Life on the margins in urban New Zealand”. *Soc. Sci. Med.* Vol. 33, No. 4, pp. 369-379.

Kronval, J (1980). *Air Tightness — Measurement and Measurement Methods*, Swedish Council for Building Research Publication D8, Stockholm.

National Swedish Board of Physical Planning and Building (1980). *Swedish Building Code with Comments*, Chapter 33, SBN 1980.

Platt, D P, C J Martin, S M Hunt and C W Lewis (1989). “Damp housing, mould growth, and symptomatic health state”. *Br. Med. J.* 298, pp. 1673-1678.

Standards Association of New Zealand. NZS 4218P:1977, *Minimum Thermal Insulation Requirement for Residential Buildings*, Wellington.

Standards Association of New Zealand. NZS 4303:1990, *Ventilation for Acceptable Indoor Air Quality*, Wellington.

Trethowen, H A (1971). *Dampness in Housing*, Building Research Association of New Zealand Research Report CR 2, Wellington.

Trethowen, H A (1987). "Air, earth, water — the sources of moisture", *Air Infiltration and Ventilation Centre Workshop on Moisture*, Wellington.

World Health Organisation (1984). *Report on a WHO meeting, August 21-24, 1984, Indoor Air Quality Research*, EURO Reports and Studies 103, Regional Office for Europe, Copenhagen.

Chapter 7
Space Heating Technologies

This chapter provides an overview of space heating by means other than by solar gain. The chapter outlines some criteria for choosing heating appliances or systems. The strengths and weaknesses of heating homes and their occupants by using either radiant heating or warming the inside air, are discussed. The question of energy efficiency in relation to space heating is addressed, and typical efficiencies of different electric, natural gas and solid fuel heaters and systems are given. Some special considerations when using combustion appliances are identified. The two main heating system options for homes — dispersed heaters versus central heating — are discussed. Subsequent chapters provide more details on electric, solid fuel and natural gas heating.

7.1 Historical Legacy

Most New Zealand houses are heated by sets of small portable heaters distributed throughout the house, or a number of small heaters fixed in the main living areas, or a combination of both portable and fixed heaters. Few houses have the central heating systems that are common (and necessary) in some other parts of the world such as Canada, USA and Europe. The distributed heaters are generally controlled manually and, when combined with the relatively poor levels of thermal insulation in New Zealand houses, lead to the lower comfort levels in homes here compared to overseas.

Recent research (Isaacs and Cullum, 1994) indicates that the top priority of new home buyers was that their houses be "very comfortable", and that this was important or very important to 95% of those surveyed. For most people, a comfortable home would be heated to between 18˚C and 22˚C. The Department of Health's recommended minimum level is 16˚C. Temperatures lower than this contribute to condensation on walls (not just windows and frames) which encourages mould and mildew growth, with a release of respirable spores, possibly leading to increased asthma and other diseases.

As people become aware of the comfort levels experienced in other developed countries and the health effects of living in underheated homes, the demand for more comfortable and healthy temperatures in houses is expected to grow. This demand could be met by continuing with the New Zealand preference for small heaters (both portable and permanently installed), but by markedly improving the choice of heaters and their placement and by ensuring they are properly controlled. A limitation for older homes, even when insulated, could be the capacity of the existing wiring. More heat input may be needed during cold periods than the house mains can supply. Options to deal with this range from rewiring, to using one or two ground-sourced heat pumps, or installing natural gas heaters or wood burners.

Alternatively, the demand for better comfort levels may lead to an increase in the numbers of central heating systems in New Zealand. These systems generally have some control and, hence, efficiency advantages over a dispersed system of several small heaters. They may also be easier to retrofit to some homes than to undertake substantial rewiring so that every room is able to run an electric resistance heater.

7.2 Design Criteria

As emphasised in the previous chapter, there is a relationship between air temperatures in homes and moisture control. To avoid condensation problems, it is desirable to have all rooms heated to a minimum background level that depends on the degree of ventilation provided.

As a general rule, the level and duration of heating can vary from room to room. Living rooms, dining areas and kitchens will need both background and, when occupied, comfort level heating. Bedrooms also require background heating, but the comfort levels may be lower than for the other main living spaces. It may be satisfactory to only heat laundries and bathrooms when occupied, providing these rooms are well ventilated and have mould-resistant surfaces. Household heating objectives will vary according to occupant preferences, age and state of health.

A number of factors need to be considered if the heater appliance or system choice is to lead to an energy efficient result that provides the levels of comfort required:

- The maximum heat output required — a function of temperature targets, living space served, building envelope characteristics (e.g. insulation) and outside climate.
- The type of heat required and aesthetic considerations — all round background heat, specific warm air sources, radiant heating, visible flames, etc.
- Budgetary constraints and other preferences — providing fixed heaters in all rooms may remain too expensive for some families.
- Getting the best use out of the heat generated — using vents, fans and ducts to obtain warm air recycling, avoiding wasteful thermal stratification, etc.
- Timing of heater output — as well as providing a minimum background standard, ensure comfort levels are made to coincide with occupancy periods.
- Flexibility — can the heat output and timing be adjusted in good time to accommodate solar gain, increases in outside temperature, etc.?
- Need for rapid heating or low thermal inertia — could some rooms be only heated intermittently due to low occupancy providing a rapid heat source is available?
- The level, or frequency, of occupant control that can be reasonably expected — are automatic controls needed?
- Indoor air quality issues, the air ventilation requirements of combustion heaters and the effect this has on space heating efficiency.
- The energy efficiency of heaters in terms of total fuel cycle (not just end use) and the variation in efficiency according to timing, level of heat output and *usefulness* of the heat.

There are several aspects relating to the overall energy efficiency of space heating, the last factor listed above. Firstly, there is the efficiency with which heat is delivered to the living space. Determining this involves working through the conversion efficiencies (e.g. gas to electricity/electricity to heat), energy storage and transport losses and so on. The full fuel cycle needs to be looked at, especially where electricity is concerned, not just the final conversion or end-use.

The second aspect to energy efficiency is harder to quantify as it relates to the usefulness of the delivered energy for its purpose. To avoid condensation, a background level of uniformly heated air may be needed in a home. When the home is occupied, it is really people that need to be warmed, not air as such. Perhaps the air and furniture could be kept at least above a minimum temperature while the occupants feel warmer due to low temperature radiant heating. The issue is how well does the heater provide the right heat at the right place at the right time? Many of the first nine factors listed above also relate to how successful the delivered heat is at providing the service needed.

Many of these factors relate to the question of heater control. The next chapter, which covers electric heating, also discusses controls for electric heaters. The points made concerning control are generally applicable to other types of heaters.

Whatever type of heating system is used in a house, attempts should be made to match heat output to needs. For the cheaper portable or small fixed heaters, a properly placed thermostat is essential. A timer is another simple device that will save energy or provide comfort when needed.

In the discussion below on the relative merits of heater types, systems and fuels, reference will be made to some or all of the above ten factors.

7.3 Methods and Fuels

There are two methods of distributing heat in houses — by heating air and by direct thermal radiation. Most heaters use a combination of air and radiant heating, but each heater type usually has a dominant mode. Even appliances or systems designed to act solely as radiant heaters eventually cause the air in a room to warm up. There are trade-offs between the two types of heating, so neither one has dominated the New Zealand market. Their general strengths and weaknesses are discussed below.

Space heating appliances can also be categorised according to whether or not they are electric or combustion heaters. Combustion heaters burn a fuel, such as natural gas, to produce hot water, warm air or radiant heat. If the source of electricity is thermal generation, then electric heating also involves combustion, but in this case at a site remote from the home. Combustion heaters in homes raise a number of special issues, and these are discussed in the next section.

Air Heating

Electric, natural gas and solid fuel heaters can be designed to primarily heat the air in living spaces. Central heating systems also mainly work by heating the air in the rooms they serve. With air heating, the hotter air tends to rise toward the ceiling, and this means that the heat ends up concentrated away from people. Typically, the heater thermostat will sense the cooler air near the floor and keep the heaters on. Thermally-stratified air also leads to "stack effect" induced infiltration, which increases both heat loss from air exchange and from conduction through the ceiling.

Methods of overcoming these difficulties include:

- careful heater thermostat placement;
- mixing the air in a room (by using a heater with an inbuilt fan or using a thermostatically-controlled low-speed ceiling fan); and
- allowing the warm air to enter a higher level (multistorey house) before being recycled, for example with an in-line fan and ducting.

Radiant Heating

Electricity and natural gas heaters can be designed to provide radiant heating. Open fires and, to a lesser extent, some types of enclosed solid burners also provide significant amounts of radiant heating. Once radiation is emitted, there is no thermal inertia; heating is instantaneous as it tends to heat people and solid objects directly rather than the air. This feature can offer some efficiency advantages, especially in open, draughty areas (e.g. workshop basements) or infrequently used areas (laundries). Air is heated to a certain extent by radiation but mostly by indirect means. The surfaces of objects (e.g. walls and furniture) warmed by radiant heat in turn warm the air.

The most common form of radiant heating is derived from a high temperature source. An electric bar radiator is the archetype. Radiant heating, especially from small high temperature sources, often provides relatively low thermal comfort due to radiant non-uniformity. As thermal radiation travels by "line of sight," the side of the body facing the heater is subjected to a high radiant flux of heat, while the other side only receives the small fraction of radiant heat (<10%) that is reflected from other room surfaces. Because the body's surface is warmer than typical room surfaces, there is a net loss of radiant heat from the shielded side of a person to the other surfaces of the room. Having one side of the body hot and the other cold is not comfortable.

Delivery of significant amounts of radiant heat requires either high temperature or large heater area. High temperature radiant heat brings discomfort from radiant asymmetry and large area, lower-temperature radiant heaters or systems are expensive. The latter can, however, deal with the non-uniformity issue, especially if several different heating surfaces, such as the floor and ceiling, are used.

7.4 Combustion Heaters

Combustion heaters are the most common alternatives to electric resistance heaters. These include built-in or portable gas burners and enclosed or open solid fuel heaters. There are issues associated with these heat sources that should be considered in heater choice and operation.

Portable LPG heaters are becoming popular in New Zealand. These have the advantage of heat outputs exceeding 4 kW, which means they can compensate for inadequate electrical wiring limiting the use of electric resistance heaters. If people purchase these heaters expecting them to be an economic alternative to electricity (or reticulated natural gas), they may be disappointed. Electric radiant heaters with a combined output of 4 kW can be less expensive than an LPG heater and bottle. Retail LPG in New Zealand is sold for about the same price, on an energy basis, as retail electricity. The marginal cost of accessing electricity is low to zero, depending on how line or network charges are recovered. Empty LPG bottles need to be taken to a filling station, which usually involves time and money.

Another potential problem is the indoor air pollution (from combustion products) that unflued heaters (LPG, CNG, kerosene, etc.) release directly into the living spaces. The most visible symptom of this pollution is the greatly increased condensation rates from the water released when unflued heaters are used. However, a more direct health problem is the toxic combustion products, such as carbon monoxide and nitrogen oxides, which are also released into the indoor environment. LPG heaters have a an antivitiation device or oxygen depletion pilot that shuts off the appliance if room ventilation is insufficient and combustion product levels become too high. The remaining concern is one of long-term exposure to pollutants such as nitrogen oxides.

The water vapour and pollutant issue can be managed by firstly using only modern, clean-burning appliances and, secondly, by increasing room ventilation rates. The latter causes a loss of warm air and it can be difficult to judge whether the ventilation is adequate to ensure pollutants are below recommended levels. At the very least, occupants should provide sufficient ventilation to avoid condensation.

Enclosed solid fuel heaters using wood, coal, or a combination of fuels, have been installed in many homes. Chapter 9 provides an overview of solid fuel heaters and their operation. The major problem with solid fuel heaters is that they can be difficult to control, and the problem is exacerbated by the use of wet wood. If they are not operated properly (with a hot fire and the right balance of combustion air and fuel), they are very inefficient. If insufficient air is supplied to a solid fuel heater, incomplete combustion occurs, leading to creosote formation (and an increased chance of subsequent chimney fire) and toxic emissions from the flue to the outside atmosphere.

It is not widely known, but the pollutants released from incomplete combustion of wood are more toxic than those from burning plastics (Sandia National Laboratory, 1981). Furthermore, burning treated timber and coloured paper releases significant amounts of toxic heavy metals (including arsenic) in the smoke. In areas where drinking water is caught as rain runoff from roofs, this can lead to serious contamination.

Many modern, solid fuel burners have improved low burn rate performance, but problems can still arise. When enclosed solid fuel heaters are loaded with fuel and then closed down to burn through the night, incomplete combustion is virtually assured. Then most of the heating value of the wood is not converted to heat, but rather to pollution. This problem can be exacerbated by “wetbacks”, where domestic water is circulated and heated in pipes within the firebox. This causes cold spots facing the fire, which assures incomplete combustion and further reduces the amount of useful heat obtained from burning the wood.

These points are not arguments against using solid fuel heaters. Using firewood avoids the use of fossil fuels and is beneficial in terms of reducing net greenhouse gas emissions. It is important that people do not counter these benefits by creating local pollution problems through poor operation of their wood heaters. Dry wood should be used, the fire should be kept burning well at all times and it should be left to go out at the end of the evening and then relit in the morning.

Flued natural gas appliances avoid pollution and energy efficiency problems. They are clean burning and, providing the flue is correctly placed, none of the combustion products enter the home.

7.5 Appliances and Efficiencies

A home heating system could consist of a number of dispersed heaters — portable heaters or fixed appliances in each room or living zone. Alternatively, there could be a central heating plant with heat conveyed to each living space — central heating. In some central systems, such as house-wide radiant floor heating using heating wires, there is no central heating plant, but there may be a central processor to control heat delivery to zones.

A major heating appliance used in an open plan home may be able to almost heat the entire home by convection of warm air, especially if attention is paid to reusing this air, recycling it with fans, etc. What separates this system from a warm air central heating system is that the latter has an enclosed and dedicated energy delivery (and, often, a return) system to virtually all parts of the house. This delivery system can consist of pipes, ducts or wires.

Dispersed Heating System

Having a dispersed heating system allows flexibility in the choice of heaters, but to be energy efficient, this approach requires good automatic controls and occupant management. A dispersed system can be built up over time, which avoids the major initial capital outlay of a central heating system.

Portable heaters, in particular, are a flexible and inexpensive approach to providing space heating. They play an important role in rental accommodation where the legal requirements for landlord-provided space heating is generally enough to avoid tenant hyperthermia, but is not adequate for proper health and comfort levels. Over-reliance on portable heaters in New Zealand could frustrate efforts toward better comfort levels and energy efficiency.

The principal problems with portable heaters are the location of the thermostats on the heaters. In many cases, built-in timer controls are absent and the heat output is limited for large living spaces or during very cold weather conditions. In the long run, it would be better if all rooms had a form of permanent heating installed, suitable for the use of the room, and well controlled for temperature, spacial heat distribution and occupancy.

Heater Types

A wide range of heater types and sizes are available to create a dispersed heating system for a home. The discussion of typical conversion efficiencies below applies to the following types of room heaters:

- electric — conventional electric heaters (including fan-assisted) and low-temperature radiant heaters;
- storage heaters;
- heat pumps;
- natural gas — flueless LPG gas heaters and flued gas heaters;
- condensing gas heaters;
- solid fuel — open fires and enclosed non-airtight burners; and
- closed burners.

Conventional electric heating takes many forms, but all operate on the principle of resistance heating: an electric current passed through a wire generates heat. Electric convection heaters (wall mounted or freestanding panel heaters), portable fan heaters, oil heaters and high temperature radiant heaters all operate with 100% end use efficiency in that the energy they consume is put into the room in one form or another. Some forms of radiant heating (for example, heat lamps for use in bathrooms) produce visible light as well as heat.

Whether conventional electric heaters are fully efficient in terms of providing the service required is another matter that depends on the circumstances of their installation and operation (for example, the issue of radiant asymmetry).

Another important consideration is the thermodynamic efficiency of the full fuel cycle for electricity. There is an argument that electricity energy efficiency will, in the main, either reduce thermal generation or defer new thermal power station construction and operation. After allowing for transmission and distribution losses, the overall efficiency of thermal power is around 30%. The overall efficiency of a new combined-cycle natural gas station can be 40% or more. It is useful to bear these figures in mind when considering the efficiencies of heaters that burn fuels directly.

The basic efficiency with which heat is put into a room by low-temperature electric radiant heating depends on whether the radiant surfaces form part of the building envelope, and, if so, how well insulated they are. Radiant ceiling panels can lose heat to the roof space above. Concrete slab-on-ground floors should be well insulated if they have hot water pipes or resistance heating elements in them.

Electric storage heaters also convert 100% of the input energy into heat. The overall efficiency of storage heaters depends very much on the pattern of occupancy in the home. If the home is not used during the day, then many types of storage heater may not be very efficient. This issue is elaborated in Chapter 8 “Electric Space Heating”.

Heat pumps are potentially a very efficient means of converting electrical energy into space heating. They essentially capture low-grade outside heat and upgrade and convey this into the house. Typically, for each kilowatt of power they consume they provide 2.0 to 3.0 kilowatt of heat. Sometimes they are combined with resistance heaters to provide rapid or peak demand in which case the unit’s efficiency will fall. More information on heat pumps is provided in Chapter 8.

Natural gas and LPG heaters can be radiant or air heaters and flued or flueless. Flueless heaters are almost 100% efficient in end use terms. These heaters require extra ventilation to provide combustion air, remove the water vapour they generate and maintain indoor air quality. They are often cited as being 90% efficient to take account of the warm air loss from ventilation.

The efficiency of flued heaters depends on the heater design, but typically varies from 70% to 90% with the higher figure being obtained by condensing appliances that recover the latent heat of the water in the heater exhaust. Flued heaters should have measures to prevent air passing through them when they are not in use, thereby removing heat from the room they serve.

Open fireplaces are not very efficient. Possibly only 10% to 20% of the energy content of their fuel gets into the room. The main mechanism for heat transfer is radiation, but the efficiency of a fireplace can be improved by installing tube-grates or similar devices. These increase the degree of air heating (see Chapter 9, “Solid Fuel Heating”, Section 9.3).

Various forms of enclosed solid fuel burners are available. The simplest of these are the classic potbelly or non-air tight stove. They heat by a combination of radiation and air heating through conduction and convection. Modern closed heaters are designed to reduce radiation (for safety and close placement to walls) and increase air heating. The efficiency of enclosed burners can vary from around 45% to over 70%, depending on both model and operation (high or low burn rates).

7.6 Central Heating

The great advantage of central heating is its convenience. It allows uniform or variable heating throughout a house with simple room monitors and controls. A single central programmable processing unit can be built into the system to control the delivery of heat according to time of day, planned occupancy (preheated for arrival from work), outside weather, etc. It can also be integrated with ventilation management.

Furnaces and Boilers

Electricity and all the other main fuels can be used in suitably designed central heating units. Oil is a common fuel in some countries. Units are even available, in Denmark for example, to run on such biomass fuels as baled straw. The central heating unit is usually placed in a basement in overseas installations. In New Zealand, plant is also available that is designed to be placed on the outside wall of a house or in a ceiling space.

Air central heating systems use either an electric or combustion furnace or a heat pump (geothermal energy is also used in New Zealand). Water based systems usually require a boiler as well as a furnace. In some very well-insulated houses, a trend is to eliminate the boiler and use a slightly larger domestic water heating cylinder as the space heating source. This is effective in reducing the capital cost of the system when the maximum heating load is small enough to be met with the water heater.

The best water and air heating combustion furnaces have efficiencies well above 90% and actually condense the water released by combustion, thereby recovering its latent heat (see Chapter 10, "Natural Gas Heating" Section 10.2). This also leads to reduced flue costs, as the flue no longer has to support high temperatures and be made of expensive stainless steel, but can be made of low-cost plastics. In New Zealand, for example, the Vulcan Powerhouse natural gas central heating unit has an efficiency of over 90%. This is designed for interior installation, is well insulation and has a low temperature plastic flue. It could be safely installed in a living room.

Air Delivery Systems

Overseas, the most common form of central heat distribution is by delivering hot air from a central furnace through a series of ducts to all rooms of a house. The main problem with forced air heating is that it increases heat loss from infiltration due to differential pressurisation and depressurisation of spaces in the house when the furnace fan is operating. Furnace fans cause positive pressures in the rooms where supply air is delivered, causing them to exfiltrate, and negative pressure in the furnace room, causing it to infiltrate. This effect is enhanced if return air ducts are small or plugged.

The furnace fan pressure is on the order of 50 to 100 Pa, about equivalent to the pressures generated by blower doors used for fan pressurisation studies of infiltration, which give infiltration rates several times higher than under average natural conditions. It is clear that air-based central heating will be more energy efficient if a house is built to a high level of airtightness, but this means that ventilation will need to be managed (elaborated below).

Air-based systems suffer the parasitic energy losses of fans, which can be high due to low fan efficiencies. The Canadian Mortgage and Housing Association has reported that forced air circulation blowers average about 10% fan efficiency. In fact, there have been some allegations that manufacturers of combustion heaters use this inefficiency as supplemental electric resistance heat to boost the perceived efficiency of their furnaces. Swedish measurements of ten fans in six buildings found a range of (fan plus motor) efficiencies from 15% to 57%, averaging about 32%. Though manufacturers' data indicated fan efficiencies should be about 50%, motors were oversized and ran at only about 60% load, which contributed to the low efficiencies.

With air delivery systems, the most cost-effective energy efficiency improvements for houses (at least in moderate to cold climates) is generally to increase the delivery efficiency of the space heating. The discussion on heat pumps in Chapter 8, "Electric Space Heating", Section 8.3 contains information on how to improve air delivery efficiencies through better fans, motors and reduced circulation friction. This information is relevant to any systems that involves forced air movement.

Air-based systems avoid thermal stratification by using return air ducts. The heat content of a large proportion of the return air can be recycled as the air is topped up and sent back to the rooms. Ventilation can be managed by adding a proportion of fresh outside air. An air-to-air heat exchanger can be used to preheat this incoming air with the outgoing air.

Hydronic Systems

A less common but more efficient method of delivering central heat is as hot water to individual rooms. The hot water is pumped through hot water baseboard convectors (usually called radiators), which are finned tubes through which the hot water flows.

Natural air convection carries the heat from the fins to the room air without pressurising the space or incurring fan power costs.

However, passive convectors may only transfer heat to the room at an adequate rate if high temperature water is used or their surface area is very large. This issue can be addressed by delivering hydronic heat to spaces by means of small fan-forced convectors, where room air is blown over a finned coil containing hot water. This forced convection heats the room air more effectively than the natural convection in baseboard radiators and helps to reduce stratification. Because both the fan supply and return air comes from the same space, this avoids the pressurisation effects caused by conventional air distribution. Using forced convectors can help reduce the thermal mass (both in radiation casing material and water capacity) in the distribution system, which is desirable for better control of heating and less overshoot.

Another advantage of hydronic heating compared to air delivery is that controlling heat delivery by zone is simplified as solenoid zone valves are much less expensive and more trouble-free than automatic air dampers.

Radiant Heating Systems

Low-temperature radiant heating on a house-wide scale constitutes a form of central heating. The two main systems are floor or ceiling heating. The house can be divided into zones with individual zone controls spread around the house or with a central processing unit to control the system. The main type of radiant central heating is floor heating using either heating wires or hot water pipes in a concrete slab or heating wires placed on a suspended timber floor. Ceiling-based low-temperature radiant heating is another approach. A central heating plant is not required if electric heating wires are used. This form of heating is discussed further in Chapter 8, “Electric Space Heating”.

Hydronic radiant floors (e.g. hot water pipes in a concrete slab) can provide great comfort, but are expensive, and the thermal mass makes them difficult to control. As mentioned in Chapter 3, “Importance of Thermal Mass”, it may be possible, however, to optimise a concrete slab-on-ground for both solar gain and radiant floor heating.

7.7 Conclusions

New Zealand homes are generally underheated. Increasing comfort levels will require action to increase heat input and reduce losses. Solar gain, insulation and careful management of ventilation are important. Careful heater selection, installation and the use of controls will help to minimise the heat input needed to gain a given level of comfort.

The choice of heater or heating system is quite complex, but a number of key factors have been identified. These can be reduced to a series of key questions: what type of heat best suits the service requirements; is the right amount of heat getting to the right place at the right time; once it is delivered, is the best use and reuse being made of it; and, finally, are there any downstream effects (pollution, increased ventilation needs, etc)?

The energy efficiency of different types of heaters, in terms of converting primary energy to space heat varies. A basically efficient heater can be applied to a task or operated in a manner that makes it inefficient. The secret is to put together a set of equipment and controls that provides the right answers to the key questions just posed.

Some heaters do not lend themselves to automatic control (e.g. wood burners). An important issue is the level of householder control that is needed or can be expected in managing space heating. Woodburners can be efficient and environmentally friendly heaters if householders are prepared to operate them properly and if any secondary heaters are controlled to fit in with the output of the woodburner.

References

Isaacs, N and K Cullum (1994). *Barriers to the Acceptance of Energy Efficient Technologies in Housing*, paper presented to CAE Energy Efficiency Workshop, Wellington, February, 1994.

Sandia National Laboratory (1981). *Solar Heating Materials Handbook — Environment and Safety Considerations for Selection*, Anachem Inc., Albuquerque, New Mexico.

Chapter 8
Electric Space Heating

8.1 Introduction

This chapter outlines some of the more important matters concerning energy efficiency issues relating to electric space heating. Conventional heater selection is discussed, which is usually the outcome of personal preferences and experience as well as consumer advice from retailers, power companies etc. New Zealanders have historically tended to favour using a number of small-to-medium-sized heaters (some, or all of them portable) over central heating systems. This approach has limitations that are discussed. Over the last few years, power companies have been actively promoting nightstore heaters. These, too, have limitations which are noted.

Two modern heating options are emerging. These are low-temperature radiant systems and heat pumps. The key features of both systems are outlined. These modern technologies are suitable for partial home heating (that is heating only selected zones) or house-wide central heating systems. These systems are not cheap, but the investment involved usually means that the relatively small additional expense of installing effective controls is seriously considered. The issue of controls for electric heating is an important subject that is discussed in Section 8.5. The general principles outlined are also applicable to other forms of heating, such as using natural gas.

8.2 Conventional Heater Selection

Power Company Advice

Figure 8.1 shows the heater selection advice typically provided by power companies to consumers in home energy audit kits or other types of advice packages (e.g. PowerDirect, 1994).

For any given room, a wide range of heater types may be suitable. This reflects the versatility of electric heating. High temperature radiant heaters are not advised for bedrooms, partly for safety reasons, but also because the occupants will get little benefit from these when they are sleeping. Radiant non-uniformity also makes these heaters less than ideal for dining rooms. If radiant heaters are used in kitchens, utility rooms and bathrooms (active "work" areas) then there is a case for fixing these high on walls for safety reasons. Heating in utility rooms and bathrooms, whether by heat lamps, normal radiant, fan or convective heaters, can be controlled by an occupancy sensor to obtain the best efficiency.

Low heat sources such as heated towel rails are often mentioned in advice packages. Low power (40 to 60 watts) cupboard heaters could also be useful in many homes to deal with lack of warm air circulation through wardrobes, etc.

In the main living areas, a wide variety of heaters may be suitable. Figure 8.1 mentions underfloor heating and heat pumps, two relatively modern developments for home heating. These two approaches are outlined in Sections 8.3 and 8.4.

From time to time, the Consumers Institute runs tests on electric heating appliances to identify the relative merits of different brands and models. Recent tests include:

- fan heaters, *Consumer*, April 1992, No 303;
- radiant heaters, *Consumer*, April 1992, No 303;

- oil-filled heaters, *Consumer*, April 1992, No 303; and
- convection heaters, *Consumer*, April 1993, No 314.

Many New Zealanders create, over a period of time, a home heating system based on a number of these different types of portable or wall-mountable heaters. This reliance on small heaters raises a number of issues that are discussed below.

The power company literature that goes with advice such as that provided in Figure 8.1 is usually helpful. The need for insulation, weatherstripping, drawing curtains, etc., is mentioned. The role of thermostats, time switches and ceiling fans is emphasised. The advice package on heater choice, however, quite often promotes one or two forms of heating. Power companies are keen to see load moved off-peak and often market nightstore heaters. The role and limitations of these heaters are often not well understood by consumers; key considerations are outlined below.

Portable Heaters

A wide range of portable heaters are available on the market, and many are designed to be readily converted to fixed appliances. Historically, bar radiators were popular as portable heaters. They suffer from radiant non-uniformity and consequently create a warm-one-side, cold-the-other-side, effect.

A common type of new heater now being sold in New Zealand is oil-filled with large fins to extend the heating surface — it works as a combined lower temperature (but still a relatively small area) radiant and unforced convective heater (some have fans built in). Oil heaters are somewhat larger in size than old-style bar radiators heaters and cause less radiant discomfort.

The other popular portable heater is a fan heater. These heat air as it is fan forced through the unit. They are thermostatically controlled and most have safety devices (overheat, knock-over, etc). Some people find the fan noise, and the odour from dust being burnt as it passes through the appliance, annoying. Thermal stratification is also an issue as the thermostat is on the heater, and, consequently, is at floor level.

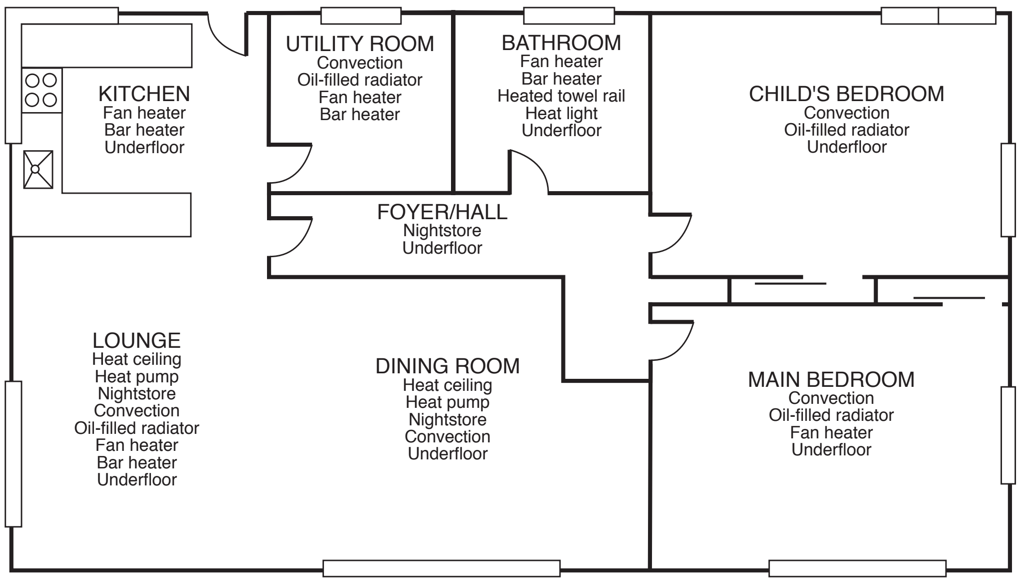


Figure 8.1: Typical home heating guide

The principal problems with portable heaters are the location of the thermostat (if any) on the heaters, in many cases the absence of built in timer controls and their limited heat output for large living spaces or during very cold weather conditions. These limitations are found on many fixed heaters as well.

Plug-in thermostats are available, but these will not be effective if the socket is close to the floor, in a draught or close to the heater. Plug-in timers are also available. Proprietary house-wide systems are available that turn appliances on and off by sending a signal through the house mains. Special power outlets are needed and the systems are expensive, although they may be included as part of a home security package. Even when time control is available, it is usually not possible to alter temperature targets at different times of the day to provide background air temperatures and then comfort levels by the time people arrive home. Some new fan heaters do have a frost protection feature which will turn the fan on when room temperatures fall below 5˚C. This means that a low background temperature can be maintained, but the setting will generally be too low to avoid wall condensation.

In the long run, it would be preferable if all rooms had a form of permanent heating installed that was suitable for the use of the room, and well controlled for temperature, uniform spacial heat distribution and occupancy timing. As outlined in Section 8.5, ideal controls have logic elements that allow for likely outside temperature changes (in advance), as well as thermal inertia and occupancy patterns. It is fair to comment that the present preference New Zealanders have for building up a heating system out of a mix of several small portable and fixed heaters does not help towards getting a well-controlled efficient space heating arrangement.

Nightstore Heaters

Night storage heaters are sold by many power companies with the incentive of lower tariffs for their use. They are time controlled and heat a thermal mass (usually a stack of bricks) at night, typically between 11 p.m. and 7 a.m. This allows the power company to shift some of its space heating load from the time of peak demand, when power is necessarily most expensive, to the night time, when the cost of power is at its lowest. The heat is released from the bricks as they cool down during the day. Figure 8.2 shows a schematic of the basic elements of a night store heater.

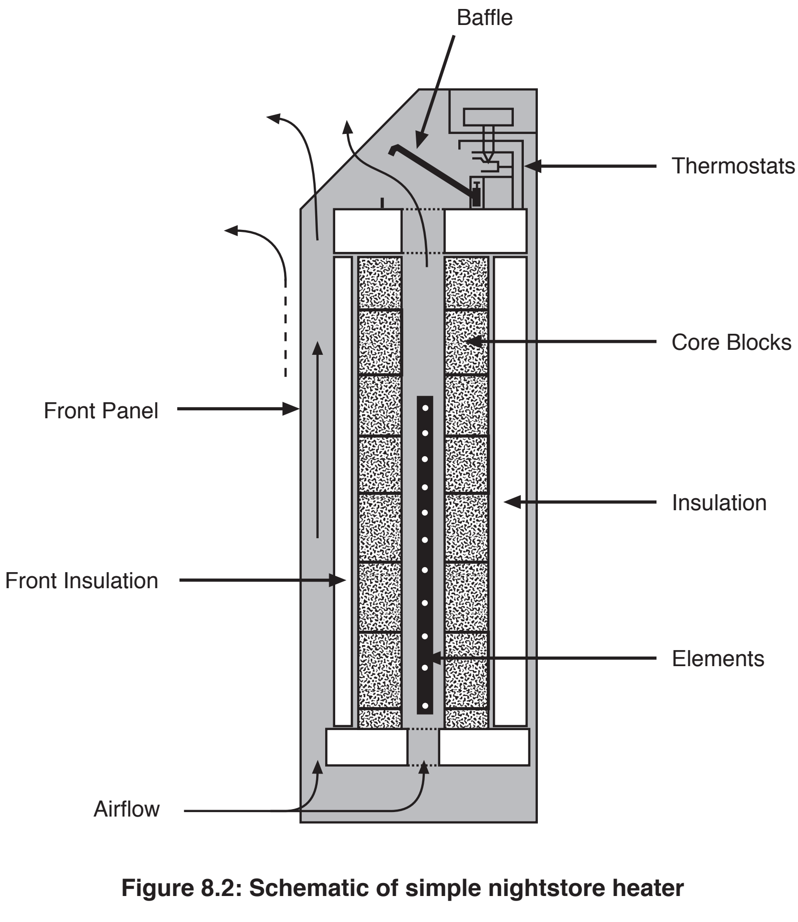


Figure 8.2: Schematic of simple nightstore heater

One technical disadvantage of nightstore heaters is that some of the heat they store (around 10%) is dissipated at night, when there is no real demand for heat. However, in underheated houses, this night-time heating may have a benefit in reducing condensation.

The other disadvantage is that simple nightstore heaters provide maximum heat output in the early morning and output tapers off during the day. Modern versions of the nightstore heater have input and output controls that are supposed to make them adaptable to different household requirements, occupancy, etc. Some have fans to rapidly extract heat if needed.

Modern storage heaters have been tested by the Consumers Institute (Consumer, 1993), which found that the main way their performance could be managed was by adjusting the input control. If a warm day is expected, then the input control can be turned down the night before. The heaters seemed to put out most of their heat early in the day irrespective of output control setting. Consequently, the Consumers Institute concluded that nightstore heaters are:

> *...best suited to houses where there is someone home during the day, especially if the house does not get too much sun. If there is no one home, much of the heat — and the money it cost — are wasted.*

The *Consumer* report on nightstore heaters also emphasised their cost (including their special installation requirements) in relation to benefits. The relatively high price of nightstore heaters and their installation may make them a poor investment for many homeowners, especially when compared to other energy saving options. The cost savings are the product of the heating energy required by the house, less the nightstore heat loss fraction and the differential tariff between day and night time electricity. This is in the order of (3000 kWh/year) x (100%-10%) x (5¢/kWh), which equals $135/year, or an eight-year simple payback for a typical nightstore heater cost of $1000.

8.3 Low Temperature Radiant Heating

The advantages of low temperature (~40˚C) radiant heating make it likely to be one of the main sources of heating future New Zealand houses. With better insulation and control, low-output large-area background radiant heaters can meet most of the heating needs of homes. Alternatively, small panels with moderate outputs could also provide adequate heating. Either way, outputs could be sized in the hundred watt range, rather than the multi-kilowatt range as at present. This means less expense.

If an optimisation was done comparing the costs of low-temperature (floor or ceiling embedded) radiant heating with extra insulation, the results might be surprising (i.e. more insulation, less expensive heater surface).

Low-temperature under-carpet heating sheets are available. These consist of heating wires sandwiched between two layers of heavy duty aluminium foil that are placed between the floor and carpet. Another option is Thermo-Floor™ (Gyp-Crete Corporation, 1994) underlay, which is 30 mm of low-R synthetic incorporating heating wires. Heating wires can also be placed over a floor and embedded in a thin layer of mortar. Either of these approaches could be used as retrofits over concrete or timber floors.

Floor heating is not likely to be energy efficient unless the floor is very well insulated. For a suspended timber floor, this would mean going beyond the minimum of draped foil insulation. Bulk fill insulation may be needed between and covering the bottom of joists to prevent thermal bridging. Alternatively, high density polystyrene could be placed between the floor and the heating wire. The effect of the heating wires, any underlay and insulation on final floor levels with respect to door sills, etc. would need to be considered.

Underfloor insulation is important, but on the other hand, floor coverings can affect the performance of radiant heating systems. Proprietary low-R carpet underlays and carpets are available.

Heating wires embedded in a concrete slab-on-ground floor is another radiant option. Hot water pipes placed in the concrete and supplied from a water heater or electric boiler unit is another approach. The concrete slab should be insulated underneath as well as along its edges. With concrete slab systems, integration or allowance for solar gain must be made. Concrete slab systems supplied from off-peak power could have similar limitations to night store heaters — best suited to homes little affected by solar gain or with all-day occupancy.

The thermal inertia of concrete slabs can be dealt with by having all or some of the radiant floor heating system thermally separated from the concrete. The heating wires could be placed in a proprietary underlay, sandwich or mortar bed, on top of 25 mm of polystyrene placed over the slab — a similar approach to a retrofit. Another option is to go to ceiling heating.

One system of ceiling heating has low power heating wires encased in plastic sheeting laid onto ceiling panels or otherwise placed between ceiling panels and the insulation above. Another alternative is the use of flat panel heaters made to look like decorative pictures. These will deliver several hundred watts from a panel smaller than half a square metre, making them relatively unobtrusive and inexpensive.

Ceiling, floor and wall heating provide unobtrusive and comfortable background heat. With all low-temperature radiant systems, thermostatic controls and timers can be used to create an efficient system. Heating can be varied from zone to zone.

8.4 Electric Heat Pumps

A heat pump is a mechanical vapour compression system used for heating. It causes heat to flow from a region of lower temperature to a region of higher temperature, opposite to the direction that heat flows spontaneously. External energy must be added via a compressor, to "pump" the heat "uphill."

A heat pump uses a circulating loop of refrigerant, which is alternately evaporated and condensed and moved between these locations (the evaporator and condenser) by means of a compressor. Most heat pumps sold in New Zealand for domestic space conditioning use ambient air as their heat source and are used to deliver warm air for space heating.

In operation, heat is removed from cold outside air by blowing it across a still colder evaporator coil. The outside air cools as it transfers heat to the refrigerant in the evaporator. The refrigerant is then "pumped" or lifted to a higher temperature and pressure in the compressor and directed to the condenser. Finally, a stream of indoor air is passed over the hot condenser surface and the air is heated and returned to the space.

The system uses two fans (one for the condenser, one for the evaporator), and the fans and compressor are powered by electric motors. The operation of the fans and compressor and the flow of the refrigerant between the condenser and evaporator are all controlled electrically.

Applications

Like other capital-intensive energy efficiency technologies, heat pumps are most cost-effective when serving a relatively continuous energy demand, such as domestic hot water supply or swimming pools used year-round, as greater energy savings are available from these higher loads. Heat pumps in houses are best used either as part of a central heating system or as the principal heater in an open plan arrangement, as they are normally too expensive to allow one heat pump per room.

The heat delivery from heat pumps is at relatively low temperature (the higher the delivery temperature, the lower the heat pump efficiency), so radiant delivery is impractical.

Most heat pumps deliver heated air, directly from the condenser coil. Heating water for hydronic delivery would also be possible, although the higher temperature requirement means a significant efficiency drop.

The most common application for heat pumps is for cooling and dehumidification, where the cold evaporator is used to deliver cooling instead of being used as the energy source for heat pumping. Refrigerators use a heat pump as do air conditioners. Reverse cycle airconditioners can provide heating as well as cooling, but are usually optimised for the latter.

Advantages and Limitations

The thermodynamics of vapour compression allow heat to be delivered at an "efficiency" of greater than 100%. The ratio of delivered heat energy to input electrical energy is defined as the "coefficient of performance" or COP of the system. Higher COPs deliver more heating for less input energy and are thus more efficient.

The efficiency limit of any cycle is called the "Carnot limit" or "Carnot efficiency", and is:

$$COP_{max} = \frac{T_{hi}(K)}{\Delta T}$$

where T_{hi} is the highest refrigerant temperature in the cycle, in degrees Kelvin (K = ˚C + 273), and ΔT is the difference between the highest and lowest refrigerant temperatures (in either degrees Kelvin or ˚C).

Real cycles do not reach the Carnot limit, due to their numerous inefficiencies. These include frictional pressure drops within the refrigerant flow path, mechanical inefficiencies and heat exchangers with finite temperature limitations.

For example, an ideal heat pump operating between 6˚C (outside temperature) and 20˚C (inside temperature) would have a Carnot efficiency of:

$$COP_{max} = \frac{293K}{14K} = 20.9$$

or 2090% efficient compared to resistance heat. A typical real heat pump operating between these temperatures will have a COP of about 2.5 (or 250% comparative efficiency).

The performance of a heat pump at various load conditions is shown in Figure 8.3. The horizontal axis shows the outside temperature at which the heat pump evaporator is acting. The top two solid lines represent the COP and the heating capacity of the heat pump. Both heating capacity and COP decline as outdoor temperature drops. During extreme conditions, the COP of the heat pump declines to 1.0, which is equivalent to electric resistance heating.

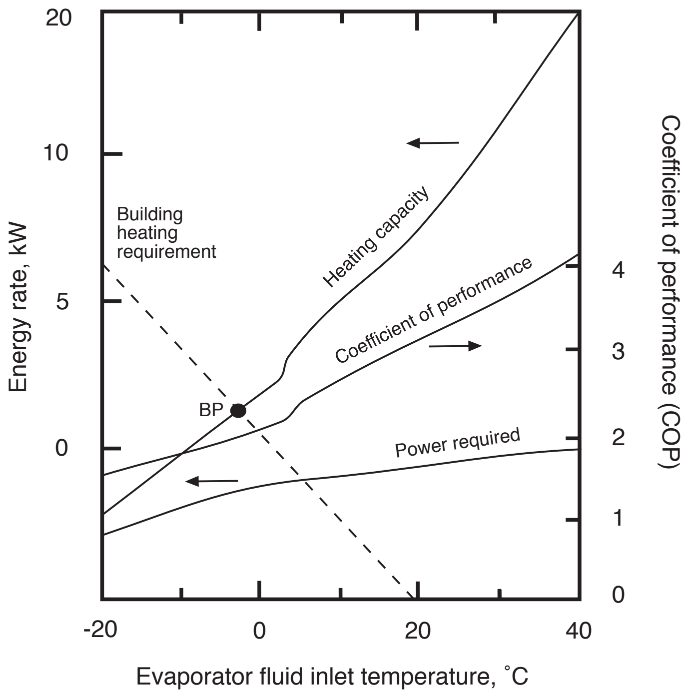


Figure 8.3: Performance of heat pumps at various load conditions (from Duffie and Beckman, 1980)

The dashed line on the same graph represents the heating load of the house the heat pump is heating. As temperature drops outside, the house heat load increases. Unfortunately, this is at the same time as the heat pump output decreases, which means that another source of heating is required on the coldest days (to the left of the point BP, the heat pump is not able to supply enough heat).

Electric resistance heating elements are normally integrated into heat pumps to overcome their reduced output at low temperatures and to automatically provide sufficient heat. Resistance heating is also used to boost output during peak demand periods, such as in the morning. However, this means that heat pumps may often be working essentially as resistance heaters, obviating their value in reducing peak electricity demand during cold periods or providing energy efficient heating.

To overcome these problems, some manufacturers have started promoting "ground-source" heat pumps. These use deep well water, or another relatively constant temperature source (water pipes deep under the front lawn may suffice), as the source of heat for the evaporator. These are more expensive to install, but draw heat from a reasonably constant temperature source and so allow the heat to be pumped at reasonable COPs all year round, even during extreme weather conditions. The peak problem of air source is also avoided.

Performance Improvements

There are many technically-feasible efficiency improvements available that have not generally been employed as the market for heat pumps has traditionally demanded the lowest capital cost. A more thorough coverage of these issues is given in *The State of the Art: Space Cooling and Air Handling*, (Houghton et. al., 1992).

Figure 8.4 shows the theoretical (Carnot) COP possible from heat pump cycles and the major losses that degrade COP to practical values, for a typical design. Real refrigerants do not give performances comparable to the Carnot efficiency, real compressors and motors have inherent losses, there is flow friction in the refrigerant, and the effective COP is only a fraction of the Carnot COP when fan power is included in addition to compressor power. Furthermore, this is based on actual refrigerant temperatures, which are respectively lower and higher than the source and demand temperatures.

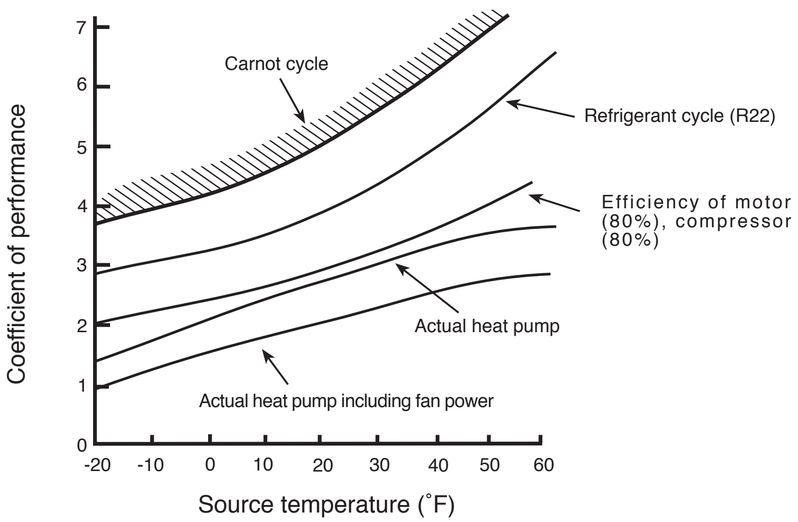


Figure 8.4: Theoretical COP from heat pump cycles (from Kreider and Kreith, 1978)

Heat Exchangers

The two heat exchangers used in heat pumps probably have the greatest savings potential. The power demand of the heat pump is directly proportional to the temperature lift imposed on the refrigerant. This is equal to the temperature difference between the heat source (outside air) and space (inside air), plus the "approach" temperatures on the condenser and evaporator.

The approach temperatures are the smallest temperature differences between the air and the refrigerant across each heat exchanger. Because heat pumps are designed for low price and small size, the heat exchangers are typically much smaller than the optimal cost-effective size for energy efficiency, and approach temperatures are in the range of 10˚C to 20˚C. These lead to significantly higher refrigerant lifts and, consequently, higher compressor energy use than systems that are optimised for cost-effective energy efficiency.

Previous experience with central chiller plants in commercial buildings has shown that oversizing the evaporator and condenser heat exchangers by a factor of three to ten times (compared to standard practice) yields much smaller approach temperatures and compressor energy savings of up to one-third at a less than five-year simple payback. Although this calculation has not been performed for domestic air-to-air heat pumps, similar results would be expected.

Fans

As mentioned in Chapter 7 “Space Heating Technologies”, Section 7.6, actual field measurements have shown that many forced-air circulation blowers operate at appallingly low efficiencies. Reasonable fan efficiencies vary between about 40% and 80%, depending on design. More efficient fans, with more aerodynamic blade shapes and smoothly-flared inlets and outlets, are more expensive, but cost-effective in terms of energy savings. As a rule of thumb, the quietest fans are the most efficient.

In general, larger, slower fans are more efficient than smaller, faster ones. Fans should be either direct drive or driven with a synchronous (cogged) belt, rather than from a friction belt (or V-belt), which increases fan power use by about 4% to 10% and reduces motor life (due to side pull on the motor bearings required to keep the belts tight).

Circulation Friction

Where heat pumps are part of central heating systems, air circulation losses can be significant. One of the most effective methods of reducing fan power requirements is to slow down the flow of air through ducts, coils and filters to reduce friction. As fan power is proportional to air flow rate multiplied by flow friction, reducing friction reduces fan power proportionally.

Friction (expressed as pressure drop in mechanical engineering terms) is approximately proportional to velocity squared, and so halving velocities (with wider filters and coils) directly reduces fan power requirements by three-quarters and has the secondary effect of allowing shallower coils for the same heating capacity, which further reduces power requirements.

Keeping coils and filters clean also shows significant energy savings. Dirty coils typically decrease energy efficiency by about 8% per year, and dust accumulation in filters has been shown to reduce airflow by about 1% per week. Coil icing (caused by humidity in outside air condensing and subsequently freezing on the evaporator) can cut performance very significantly, eventually causing heat pumps to overload.

Reducing the friction of refrigerant flow through the compressor, heat exchangers and connecting tubing via reduced velocities and improved aerodynamics also has savings potential, but is hard to quantify due to the proprietary nature of current designs.

Motors and Controls

The small motors used on fans and compressors in typical heat pumps normally have efficiencies in the 50% to 75% range. Better motors have much greater efficiencies, up to 85% or more, even in small sizes (1 kW or less). The cost premium of more efficient motors is repaid more rapidly for systems in more constant use.

Due to the aerodynamics of rotating machinery (including fans and compressors), a reduction of flowrate in a given system gives power savings proportional to the cube of the flowrate reduction. This means that for a fan or compressor with speed control, halving the load will halve the speed and reduce power use by seven-eighths. Conversely, for a system running under on-off control, halving the load will run the machine half the time and switch it off half the time, halving the power consumption. Thus the speed-controlled system will save more energy than on-off control.

These savings occur only at part loads, but yield very large savings under these conditions, which correspond to the most common conditions at which heat pumps operate.

Refrigerant

Chlorofluorocarbon refrigerants (CFCs) have come under criticism for their role in destroying atmospheric ozone and for their contribution to the greenhouse effect. Indeed, their long life makes them appear to be one of the most damaging pollutants in common use in the biosphere. To overcome this, hydrochlorofluorocarbon refrigerants (HCFCs) are used as replacements for CFCs. HCFC-22 is the most commonly used refrigerant for modern heat pumps. Although it is an order of magnitude less damaging than CFC-11, it is not clear whether this is good enough in terms of potential environmental damage.

There are other refrigerants that have no ozone depletion potential, including HFC-134a, HFC-152a and ammonia. There are trade-offs in slightly reduced equipment capacity and energy efficiency, and they are incompatible with various synthetic materials. Their use as direct replacements in existing machines are therefore limited, but there are no apparent technical problems in designing machines specifically for these refrigerants.

The amount of refrigerant in a heat pump (known as the refrigerant charge) is another important consideration in ensuring energy efficiency. Heat pumps should be charged with a weighed amount of refrigerant, rather than just charging "by feel", as is commonly done.

A California study showed that only 50% of air conditioners and heat pumps were charged to within 20% of their design charge, and that a 20% over- or under-charging led to a 21% to 27% efficiency loss. Some were overcharged by several hundred percent, which would lead to very early compressor failure, as well as the resultant efficiency penalties.

8.5 Controls for Electric Heating

Most New Zealand electric heating systems are controlled by a simple on-off switch, which the occupant manually turns on when they want heat and manually turns off when they leave the area or think the area is warm enough. Several problems arise from controlling heating systems this way:

- Areas are not warm when they are first occupied. Rooms remain cold for some time after the heaters are switched on, due to the thermal lag of the heaters and the space.
- Condensation and mould can occur if room temperatures drop below about 16˚C, which can cause significant health problems.
- Overheating can occur if heaters are left on after spaces are warm enough.

Various forms of heating controls can be applied to overcome these problems. Such controls include thermostats, zoning, time clocks, optimisers and compensators.

Thermostat

The simplest and most basic heating control is a thermostat — an adjustable switch with a temperature setpoint that turns the heating on whenever the temperature is below the thermostat's setpoint, and turns the heating off whenever the temperature is above it. If such thermostats worked perfectly, they would keep the temperature of the space (actually, the temperature of the thermostat) to within a small amount of the setpoint temperature.

Real-life thermostats have some hysteresis, or overshoot, so they don't respond instantaneously. Typically, they have a "deadband" of one or two degrees, to allow a lag time and keep the heating system from rapidly switching on and off. This deadband is not normally noticeable, as temperature variations of one or two degrees Celsius are not perceptible to most people.

Figure 8.5 shows the effect of a heater with a thermostat keeping a room at 20˚C on a night when it is 10˚C outside. The top (solid) line shows the indoor temperature, the lower (broken) line shows the outdoor temperature and the height of the columns shows the energy delivered by the heater. The fine dashed line running through the indoor temperature line is the thermostat setpoint. Time is shown on the horizontal axis, from 6 p.m. until midnight. Figures 8.6 to 8.14 follow the same format.

Under these conditions, the steady state heat loss of the room is 600 W, so a standard 1200 W heater will run half the time. When the heater is operating, the room temperature rises slowly, and when it is off, the temperature drops slowly. When the temperature is about 0.5 degrees below the setpoint, the heater switches on, and when it is about 0.5 degrees above the setpoint, the heater is shut off for the night and the room temperature drops consistently.

Figure 8.6 shows the same situation, but with a lower outside temperature. At 5˚C outside and 20˚C inside, the same room requires an average of 900 W of heating. Thus, the heater is on about three-quarters of the time to maintain the room at 20˚C.

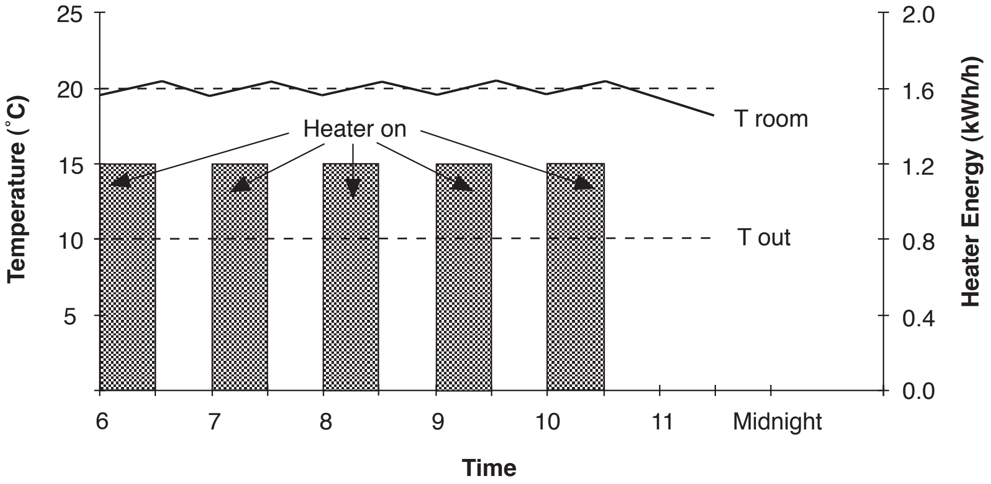


Figure 8.5: Temperatures and energy use in a thermostat equipped room at 10˚C outside

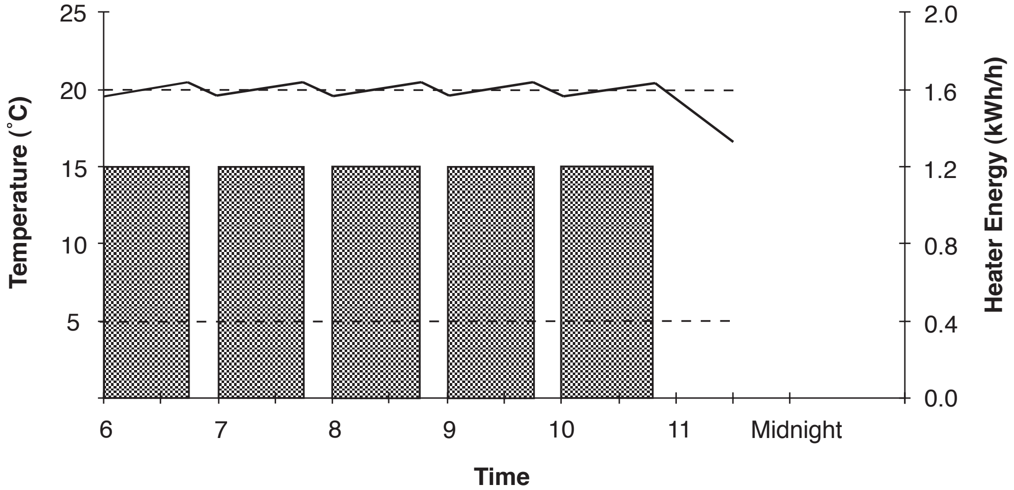


Figure 8.6: Temperatures and energy use in a thermostat equipped room at 5˚C outside

Some systems have multi-stage thermostats (such as heat pumps, which have resistance heating to back up the heat pump when the heat pump's output is too low), with two different setpoints about a degree apart. These are most commonly used to increase heater output if the normal output cannot by itself maintain the chosen setpoint temperature.

Thus, the primary heater (for example, a heat pump) works alone if it has sufficient capacity to maintain the setpoint, but if the full normal output of the heater is not sufficient, a second stage of heating (normally electric resistance with a heat pump) is switched on. This extra heat output is normally enough to maintain at least the lower setpoint.

Figure 8.7 shows the effect of a small heat pump (750 W output) heating the same room as in Figures 8.5 and 8.6 when the outside temperature is 10˚C. This is the normal situation, where the heat pump has sufficient capacity to heat the room without its booster heaters. The two-stage thermostat has not been activated in this case.

Figure 8.8 shows the effect of a two-stage thermostat, when the heat pump's capacity is not large enough to maintain the room at 20˚C (the primary thermostat setpoint). In this case, the second stage of the thermostat senses that the room temperature has dropped below its setpoint and switches on second-stage heating. The two short spikes are 1.2 kW of resistance heating, which are intermittently required to raise the temperature above the lower setpoint of 19˚C. The heat pump operates continuously, as the room temperature never reaches 20˚C.

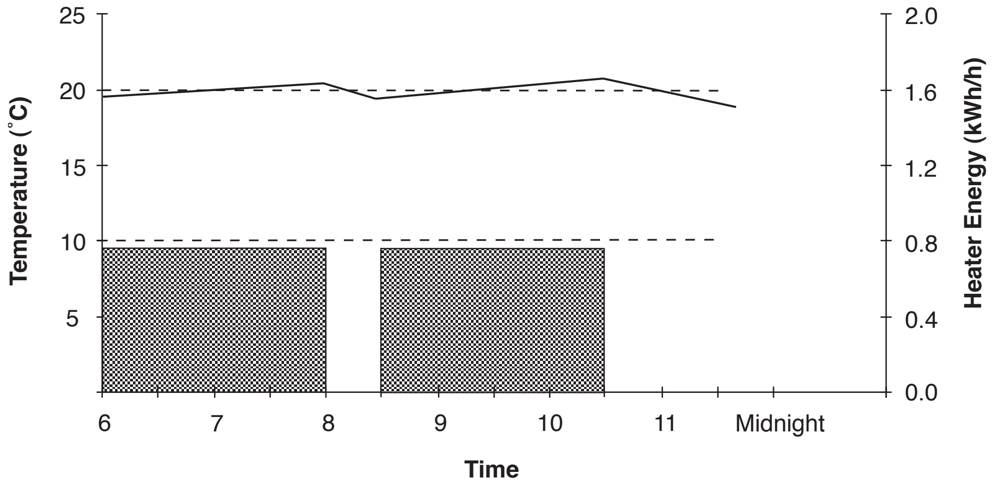


Figure 8.7: Room maintaining 20˚C with heat pump alone

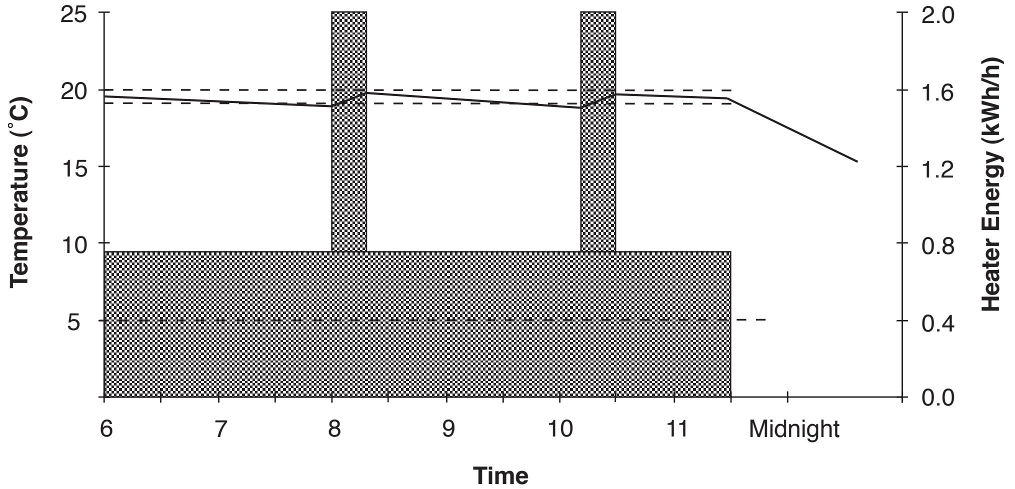


Figure 8.8: Room maintaining only 19˚C with second-stage (resistance) heaters

Of greater significance is the effect of two-stage thermostats controlling a heat pump when it is raising the temperature of a house or other space. In this case, unless the second stage is set much lower than the first, or the house hasn't cooled more than about a degree (unlikely), the second stage is always triggered and the energy saving effect of the heat pump is lost. Most of the heating of the house is accomplished by resistance heaters, negating the energy savings potential of the heat pump.

Zoning

Thermal zoning is crucial to avoid heating areas that don't need to be heated. In the typical New Zealand situation of distributed heating, individual zone temperatures are controlled manually, but as greater thermal comfort is demanded and central heating becomes more common, good control will become more important.

In central heating systems, it is important to position the thermostat where it will measure representative conditions throughout the entire space to be heated and not be affected by the heater itself or other sources of heat. A classic example is in passive solar houses with central heating where thermostats controlling the heating for non-solar rooms have been located in sunny rooms. In this case, the thermostat senses the warmth from the sun and switches off the heat for the rest of the house, which may not be heated by the sun. This situation can cause wide variations in temperature between occupied rooms and uncomfortable conditions in rooms not heated by the sun.

A common fault of low-cost central heating systems is that all rooms are served from one central heat source controlled by one centrally-placed thermostat. In such cases, some rooms are heated that do not need to be heated, and some rooms that need to be heated may not be, as described above. This leads to both excessive energy use — some spaces are kept too warm for comfort and some spaces are kept too cool for comfort. These types of problems may have contributed to the relatively low level of acceptance of central heating in New Zealand. This can be overcome by a slightly more sophisticated control system, where individual zones (rooms) have individual heat delivery circuits controlled by individual thermostats.

Theoretically, thermal zoning can be accomplished with any type of system, but practically it is only done with hydronic heating (where hot water is circulated and automatic, solenoid-operated zone valves are used) or low temperature radiant heating (where individual thermostats are used). With forced air delivery systems, zoning with thermostatic control is much less common, due to the complexity and cost of automating air dampers. Even in commercial buildings, zone temperature control actuated by air flow dampers is difficult and problematic.

Time Clock

Another control type that is very useful is a timer that can be used to control the time heating is allowed to be on. These are often used in conjunction with a thermostat to give more precise control over heating levels.

Time clocks can be used to preheat the living spaces before the family rises in the morning. Otherwise, as the house temperature drops to approach the outdoor temperature, the house will be uncomfortably cold in the morning under some winter conditions, as shown in Figure 8.9.

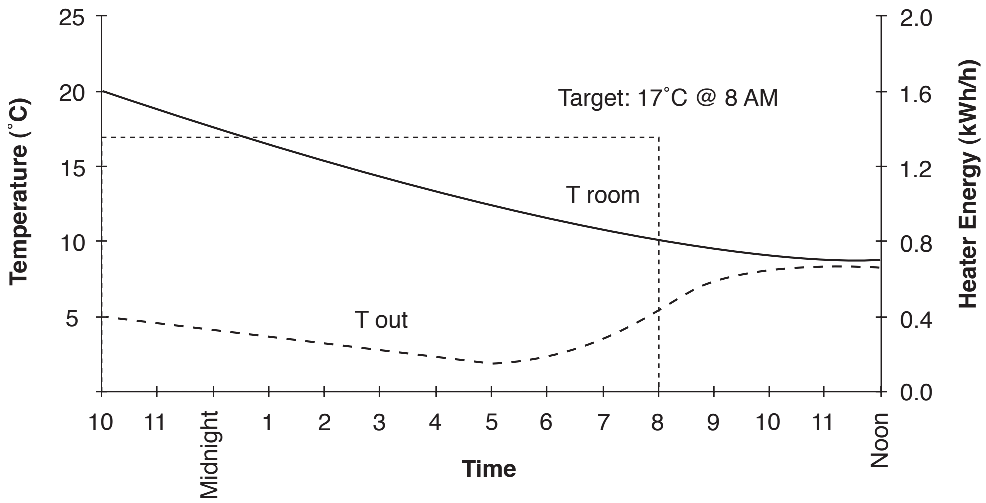


Figure 8.9: Room cooling overnight with no heating

The effect of a time clock is shown in Figure 8.10, where the heater is switched off in the evening but automatically switched back on at 3 a.m. to preheat the living spaces to 17˚C by 8 a.m. The same time clock could also be used to switch the heating off automatically at (say) 10 pm, to avoid wasting heat during the night when the rooms are unoccupied.

One disadvantage of this simple system is that time clocks do not discriminate between cold and warm nights, and switch on heaters at the same time every morning. If the heater on-time is chosen for an average night, the house will be warmer than required on mornings after mild nights, and colder than comfortable on mornings after cold nights. Figure 8.11 shows the effect of the time clock setting from Figure 8.10 (for a cold night) on a warmer night. In this case, the same time clock would preheat the room to 22˚C, which might be uncomfortably warm at 8 a.m. This would also use more energy than necessary.

A better system would combine a thermostat with a time clock to avoid overheating the room. Figure 8.12 shows the effect of this, where the heater would be switched on and off to keep the room from exceeding 17˚C. Besides avoiding the discomfort of overheating the room, this would also save about 40% of the heating energy. However, this system still has the disadvantage of using purchased energy to heat the room during hours when it is not needed. Although the room does not exceed 17˚C with the thermostat, there is no need to heat the room from 4 a.m. until 8 a.m. when it only needs to be heated at 8 a.m.

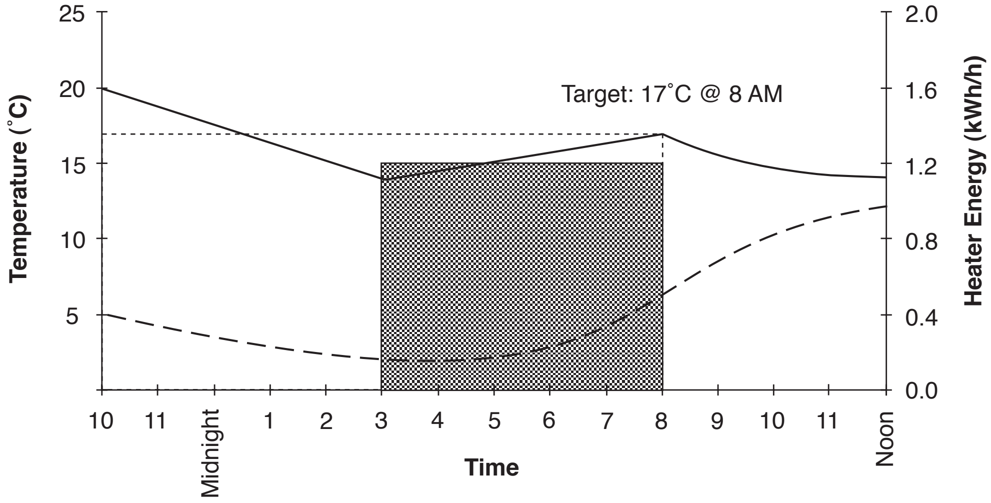


Figure 8.10: Room preheated to 17˚C with time-clock-controlled heaters

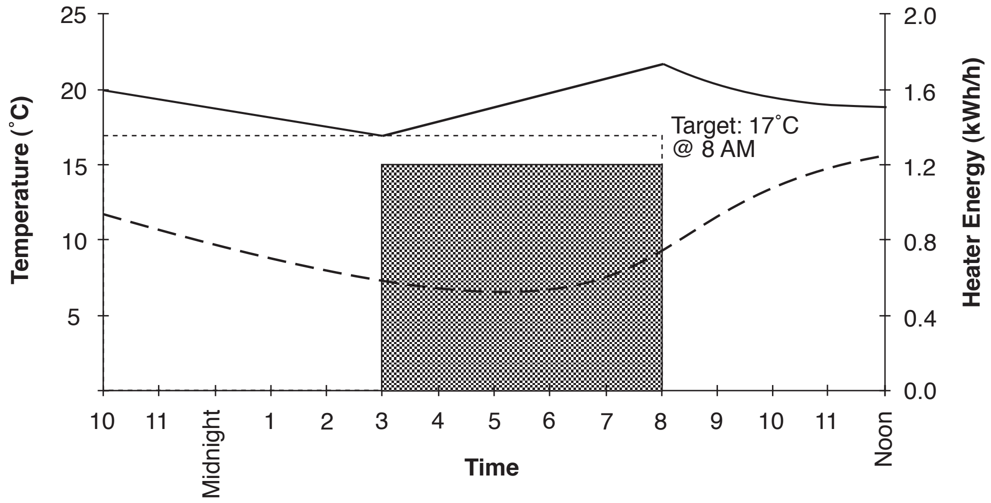


Figure 8.11: Same time clock setting preheats room to 22˚C

A more sophisticated system would integrate the time clock with a thermostat to automatically "setback" the temperature at night to a lower temperature compared to during the day. Such a system would automatically control the temperature of living spaces to healthy levels (16˚C) at night and comfortable levels (20˚C) during the day at minimal energy cost. A time clock added to a two-stage thermostat to "lock out" the second stage during morning heat up would save much of the running cost and the heat pump would run more efficiently.

Optimiser

A further refinement of the thermostat/time clock combination would automatically vary the time that the heating level was raised to the higher temperature, depending on the heating needs of the house. As the heating needs of the house are directly related to the outside temperature, such a system could read the outside temperature, then begin raising the inside temperature earlier on colder mornings and later on warmer mornings so that the inside temperature reached a comfortable level at the same time every day.

A system called an "optimiser" senses the outdoor temperature and chooses the optimal time to switch the heater on so that the room is just warm enough by the time it is needed. Figure 8.13 shows the effect of an optimiser, where the heater is switched on fully and the room is brought up to temperature just when needed. Under these conditions, this system saves about 60% of heating energy use compared to the simple time clock in Figure 8.11, and about 30% compared to the time clock and thermostat in Figure 8.12.

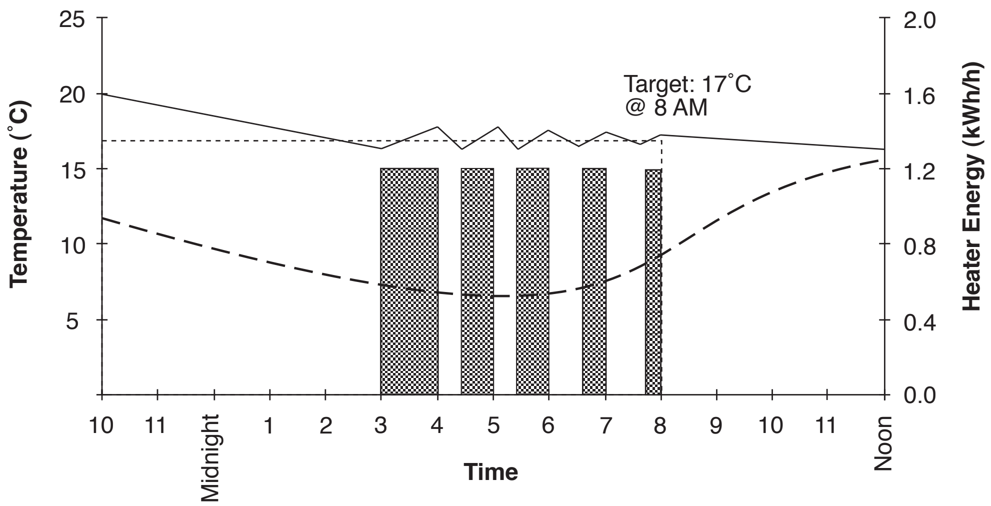


Figure 8.12: A time clock and thermostat preheat room to 17˚C regardless of weather

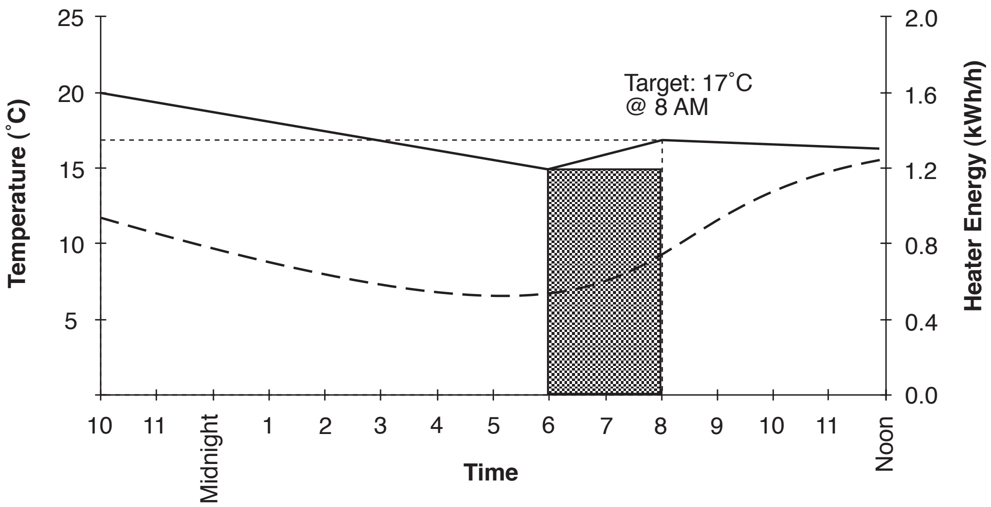


Figure 8.13: An optimiser preheats room to 17˚C at 8 a.m. without using excess energy

Optimisers are commonly used only in commercial situations because they are both complex and expensive, partly due to the installation requirements of the outdoor temperature sensor. They are, typically, adjustable for the heat loss of the space and the desired temperature and have solid-state memories to allow them to "learn" the thermal response of the space and heating system they control.

In time, it is expected that simpler systems will become available. For example, one system has been suggested by Mr Frank Pool of EECA, which would achieve much the same result without the outdoor temperature sensor. The system would compare the temperature drop of the space each night with how long it took to heat up again every morning, and use logic and a memory of the space's thermal response to choose when to start the heating. Because this would rely on a secondary measurement (indoor temperature drop) instead of outdoor temperature, it may not be quite as precise as a standard optimiser, but would achieve similar performance for a fraction of the cost.

Compensator — Proportional Control vs. On/Off

Another type of heating system control is a compensator, which adjusts the heat delivery (temperature of circulating water, power delivered to panel heaters, etc.) as a function of heating demand (usually proportional to outdoor temperature). Compensators are most commonly used in commercial heating systems with boilers, where the boiler water temperature is adjusted based on the load.

Figure 8.14 shows the effect of a compensator on the thermal response of a room. The temperature is held much more constant than the situations shown in Figures 8.5 and 8.6, and the heaters do not need to switch on and off.

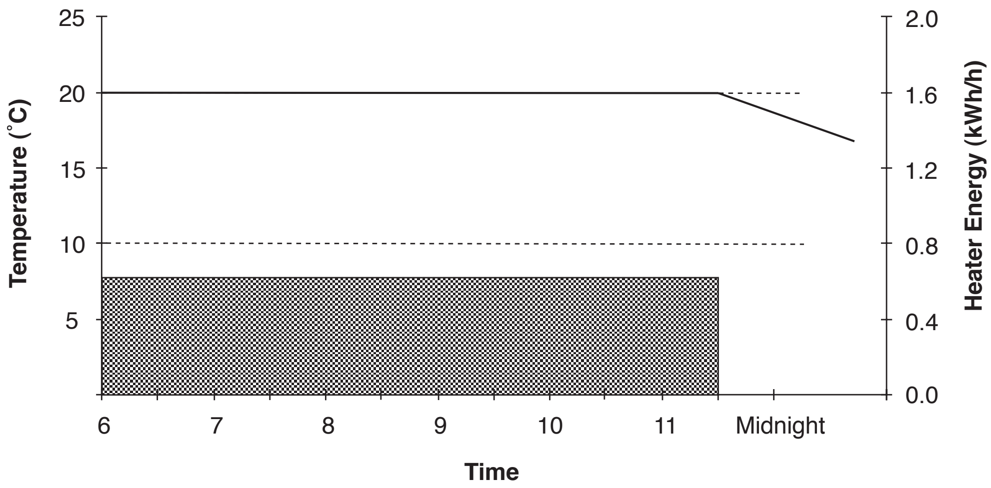


Figure 8.14: A compensator maintains room at 20°C without switching heat on/off

In electric heating systems, a compensator would be most appropriate where it could reduce the auxiliary energy use (fans, pumps, etc.) rather than throttling them on and off. Controlling their capacity with variable speed drives allows significant reductions in energy use.

If a furnace heating system can throttle, or rather modulate, then the start/stop inefficiency (largely caused by the hot flue sucking air through and cooling the mass of the firebox and tubes in thermal systems) is significantly reduced. This issue is discussed in Chapter 10 "Natural Gas Heating".

8.6 Conclusions

There is much room for improving heating systems in New Zealand houses, in terms of both delivered comfort and efficiency. At present, New Zealanders rely too much on small dispersed heaters, often portable units. Even with built-in thermostats and timers these appliances have shortcomings. They are not the most energy efficient approach to electric space heating and are not likely to provide a high standard of indoor temperature control. Nightstore heaters also have limitations on use that may not be widely appreciated. These appliances are best suited to homes occupied all day rather than those with irregular or only evening occupancy.

In the future, New Zealand houses with electric space heating will probably use low-temperature radiant heating and centralised heat pumps, with control of the heat delivery amount and time by zone. These technologies are available overseas and will become more widely used in New Zealand over time.

Improved controls offer much better thermal comfort and health, as well as significantly reduced energy costs from electric heating systems. These will become more important with the advent of central heating and heat pumps. Simply using a heat pump like a traditional New Zealand electric heater (with intermittent heating) will negate most of the energy savings available from heat pumps. Using various types of logic controls to optimise performance, such as heater start time for morning warm-up, could provide the highest performance at the lowest cost.

References

Consumers Institute (1992). “Test — fan heaters”, *Consumer*, No. 303, April 1992.

Consumers Institute (1992). “Test — radiant heaters”, *Consumer*, No. 303, April 1992.

Consumers Institute (1992). “Test — oil filled convection heaters”, *Consumer*, No. 303, April 1992.

Consumers Institute (1993). “Background heating — storage and panel heaters”, *Consumer*, No. 314, April 1993.

Duffie and Beckman (1980). *Solar Engineering of Thermal Processes,* Wiley Interscience.

Gyp-Crete Corporation (1994). *High Capacity Infloor Heating Systems*, promotional material from Gyp-Crete Corporation, Hamel, Minnesota, USA.

Houghton, D, et. al. (1992). “The state of the art: space cooling and air handling”, *E Source*, Boulder, Colorado.

Kreider and Kreith (1978). *Principles of Solar Engineering*, McGraw Hill.

PowerDirect (1994). *Home Energy Audit Kit — How to Get the Most out of Electricity and Save Money in the Process*, Energy Direct Corporation, Lower Hutt.

Chapter 9
Solid Fuel Heating

9.1 Introduction

At present, solid fuels (coal and wood) provide approximately one third of the total energy used for space heating and approximately 5% of total energy used for water heating.

There are over 352,000 enclosed fires and 322,000 open fires installed in New Zealand's 1.1 million homes (Department of Statistics, 1992). These consume approximately 100,000 tonnes of coal (including lignite) and more than 300,000 tonnes of wood each year.

There are 14 significant manufacturers of solid fuel heaters in New Zealand. In the 1992/93 year, 30,000 heaters were manufactured, the majority of which were exported. New Zealand manufacturers are leaders in the design of free-standing stoves and pioneered the double burn concept. In the first half of 1993, solid fuel heater sales reached a ten-year high, reflecting people's concerns about the electrical power shortages of the previous year and the anticipated rise in prices for the domestic consumer due to restructuring in the electricity industry.

This chapter starts with a discussion of the energy efficiency and related issues associated with using wood and coal and other solid fuels. The main types of solid fuel appliances are then outlined, tracing developments from the open fireplace to modern controlled combustion enclosed heaters. Section 9.4 outlines the standards applicable to solid fuel appliances in New Zealand and describes the test facilities set up at Coal Research Ltd, Gracefield, Lower Hutt. The results of tests carried out on 10 different wood burning heaters are summarised. The heater manufacturers and models are not identified, but a number of important points are drawn from the results.

9.2 Fuel Options and Issues

The two main solid fuel options are wood and coal (and coal derivatives). Wood and coal have different combustion features, and consequently stoves can normally only be optimised for one fuel or the other. Dual fuel heaters that provide the flexibility of using either fuel are available. While the inherent design of the stove plays a role in how efficiently it converts fuel into space heating, other factors such as the state of the fuel, how the stove is operated and the details of its installation can be dominant. A brief introduction to some of the issues involved in using combustion heaters was provided in Chapter 7, "Space Heating Technologies", Section 7.4. More information is provided below.

Firewood

Compared with coal, wood has a fairly open cellular structure containing a lot of air, which is an advantage. On the other hand, wood can contain a lot of moisture, which must be driven out before the wood will burn effectively. Fresh cut wood can contain 50% moisture, and its net energy potential will be around 7.5 GJ/tonne. If the same volume or initial mass of wood is fully dried (oven drying would be needed), it could deliver over 9.5 GJ (19 GJ/tonne). Seasoning wood by protecting it from rain and allowing it to air dry (ideally in a sunny spot) could lower the moisture content to around 20%. At this point, the original volume of green wood could deliver about 8.7 GJ (14 GJ/tonne), or over 15% more useful heat than when fresh cut. The benefit of using seasoned wood is amplified by the potential for improved stove operation.

Excessive moisture in wood can cause condensation in the flue and the deposit of creosote. This blocks the flue and increases the likelihood of later flue fires. Moisture can also lower the firebox temperatures to the point where efficient combustion is no longer possible. This is a particular problem when the stove is operated at a low burn rate or is filled for overnight burning. Modern stoves can provide good efficiency at low burn rates when using seasoned timber. Overloading the stove and shutting down the air supply overnight is a challenge for all wood stoves. It compromises energy efficiency, produces little space heat and instead often creates local air pollution. The advantage, avoiding the need to restart the fire in morning, is not worth the disadvantages. Restarting a wood stove with dry kindling is straightforward.

Different types of wood can be used as fuel. In fact, proprietary reconstituted wood fuels are available. Most people still use sawn and split timber. Overseas, special stoves have been developed to burn woodchips or woodchunks (small billets about 100-150 mm long) or pellets made from sawdust. These materials facilitate automatic fuel feed systems. Other non-wood biomass such as straw (used in Denmark, for example) can also be burnt in automated domestic furnace and boiler units.

Hardwoods, such as manuka, have a close cell structure and higher density than softwoods and consequently require a longer seasoning period. They have the advantage of burning more slowly than seasoned softwoods, resulting in less refuelling. Softwoods such as radiata pine provide a quick, hot fire (per kilogramme, both manuka and pine put out a similar amount of heat , but the rate of delivery varies). To reach a well seasoned state, wood should be air dried under cover for 9 to 12 months, depending on the species and how small it has been cut.

Wood such as radiata pine from plantations, woodlots or old shelter belts, can be considered a sustainable energy resource. There are some fauna and flora habitat and soil conservation issues involved but, from an energy perspective, this source of wood is attractive. The energy input into planting, growing and harvesting exotic plantations, and then cutting up and delivering the firewood is likely to be less than 10% of the energy content of the timber. Trials are underway in New Zealand into short rotation coppicing firewood systems. These provide a quicker return on investment than long rotation systems. They are more energy intensive, but the proportion of fossil fuel use to firewood output is likely to be less than 20%.

The use of native timbers for firewood evokes nature conservation concerns. Laws only allow the harvest of native timber on a sustainable basis and for most forest types this is interpreted to mean the occasional removal of a large tree. This practice is only economic for high value timber production, not firewood. The Resource Management Act (1991) also limits the clearance of scrub.

There are many places in New Zealand where manuka, a common firewood, could be grown sustainably. Each time it is harvested, resident native fauna would be destroyed or displaced. Rapid recolonisation of the next manuka rotation could be expected, though, especially if this habitat type was present nearby. The principle issue seems to be that existing tall manuka and kanuka stands are considered a form of native forest, or that they represent a vital step towards the re-establishment of native forest on cleared land, and therefore are protected by the law. At the moment, manuka is available as a firewood and individual consumers concerned about these issues can either avoid buying it or question its source before making a decision.

Treated timber and, to be on the safe side, painted timber (lead and other toxins) should not be burnt in domestic space heaters. Some plastics can be safely burnt, but again, a cautious approach would be to avoid all these materials. Newspapers make good fuel. They need to be tightly rolled and bound with a soft wire to avoid rapid combustion. The energy content of air dry newspaper is around 17 GJ per tonne (better than seasoned wood). From an energy viewpoint, burning newspapers to recover the energy could often be better than paper recycling. Again, to be on the safe side, highly coloured magazine papers and junk mail should not be burnt in an urban environment. The coloured inks could contain heavy metals or burn to produce toxic materials. If rainwater is collected from roofs, then a more cautious approach to what extra materials are burnt in a wood stove should be adopted.

Coal and Coal Derived Fuels

There are three main types of coal mined in New Zealand. Lignites, or brown coals, are relatively young and have a high moisture content. They are slow burning and have a similar net energy content (12-14 GJ/tonne) to seasoned wood. Sub-bituminous coals are also slow burning, they vary in their energy content (17 to 24 GJ/tonne), but provide more heat than lignites. Bituminous coals burn fiercely and fast. They generate higher temperatures than other coals and can damage the metal components of stoves.

Coal has a dense structure compared with wood and contains virtually no air. When wood burns, it leaves little ash whereas coal leaves clinker or coke. To ensure a good air supply to the burning coal, the firebed is usually on a grate. Wood burners often have a hearth with no grate. The draught created by the flue draws air through the grate and the firebed. This air also cools the grate and prevents damage from overheating. Regular removal of clinker from the grate is need to prevent heat damage to the grate and to ensure efficient combustion of the coal.

Coal can be converted into a number of fuel derivatives. The main ones available in New Zealand are coke and moulded char (e.g. carbonettes). Coke is the solid residue obtained from coal after removal of the volatile material by destructive distillation. It was once commonly used as it is the byproduct of town gas production. It is a clean burning material similar to charcoal. Carbonettes are produced in a similar manner to coke except that sub-bituminous coal is used and the resulting char is moulded into large pellets with the aid of pitch or bitumen.

Like wood, all coals and coal derivatives should be stored so that they do not become wet.

Coal stoves can burn wood and other materials, but the cautions above concerning burning treated timber, coloured paper and plastics, etc. apply. Extensive coal burning in domestic stoves is associated with air pollution in many parts of the world. Some European cities, such as Edinburgh, have switched to natural gas and are now cleaning the blackened facades of old buildings. Generally this is not a problem in New Zealand, but some places have found it necessary to regulate the use of coal and wood stoves in homes. In Christchurch, for example, where an air inversion can trap smoke for extended periods, the use of coal and wood stoves is restricted.

Of all the fossil fuels, coal creates the most greenhouse emissions per unit of energy output. It is more energy efficient, though, to burn coal in a well-designed home burner than in a power station to create electricity for conventional electric space heating. If the electricity was used for a heat pump, the situation would be different. As noted above, on a full life-cycle basis burning wood causes very little net greenhouse emissions. Environmentally, though, wood burning is often confused with coal.

9.3 Solid Fuel Stoves

Types of Appliances

A wide range of solid fuel stoves or heaters are available and each piece of technology has it own set of characteristics and energy efficiency potential. The technologies discussed below are:

- open fireplaces;
- open fireplaces with inserts;
- enclosed non-airtight heaters — freestanding or inbuilt;
- controlled combustion heaters — freestanding or inbuilt;
- improved controlled combustion heaters;
- heaters with catalytic convertors; and
- central heating systems.

Open Fireplaces

Although a large number of designs and different construction materials are available, they tend to share the common characteristic that the air supply drawn from the room is far greater than that required for combustion of the fuelwood. Although open fires create a very pleasant atmosphere, they lose a large amount of heat up the chimney (see Figure 9.1). The only heat supplied is radiant heat from the coals and flames. Attempts can be made to slightly increase the radiant output by installing metal reflectors at the back of the fireplace.

An open, freestanding metal fireplace (metal hood and flue over an open masonry hearth) allows radiant heating in several or all directions. Nonetheless, the efficiency of open fireplaces can range from zero (radiant heat does not compensate for warm air loss) to perhaps 20% due to the loss of room air and lack of air warming. One method that would improve the efficiency of an open fireplace would be to place an adjustable air intake on the hearth so that outside air was drawn to supply as much combustion and excess air as possible. When not in use, chimney draughts should be reduced by shutting any air intakes or chimney dampers and placing a neat-fitting solid screen over the fireplace.

In the past, the operational design and construction of a fireplace has required precise trade skill to achieve best operation — smokefree and a net heat input to a room. Modern architectural practices tend to concentrate on the decorative rather than the functional aspects of modern fireplaces, leaving these structures in urgent need of added appliance technology to achieve functional heating efficiency.

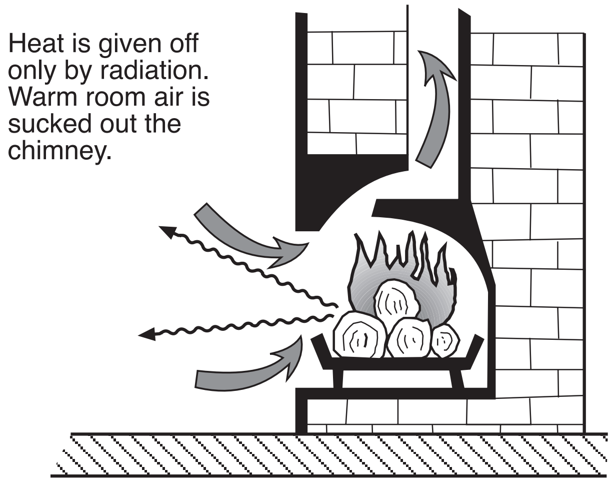


Figure 9.1: Open fire (Ministry of Energy, 1983)

Fireplace Inserts

Devices are available that are designed to recover some of the heat from an open fire by arranging an air flow through pipes or ducts installed around the fire, to heat the room.

A range of metal fireplace inserts are available for building into open fireplaces that use various kinds of heat exchange systems to boost the heat output from the open fire. Some of these have a double-skinned metal air chamber around the firebed through which warmed air is naturally convected or fan forced back into the room or other rooms. The simplest type of insert is the tube grate system shown in Figure 9.2. Most inserts are refinements of this device. Although with these systems most heat loss still occurs up the open flue, efficiencies can be increased to as much as 30%.

Enclosed Non-airtight Heaters

These represent an improvement over the open fireplace. They are usually freestanding, made of steel or cast iron and configured as vertical cylinders (pot belly stoves) or boxes.

The common feature of these types of heaters is that air enters through small gaps between the doors, ash removal trays, etc., as well as through controllable air inlets. Nonetheless, the amount of excess air used, and hence warm air drawn out of a room is less than for an open fireplace. These heaters radiate heat into the room from their very hot outer surfaces and are good for heating people in draughty, uninsulated and open areas such as large rooms, workshops, recreation areas, alpine and tourist facilities (a safety shield is needed to help prevent people contacting the stove).

Pot Belly-type stoves also heat interior air via conduction and convection from surfaces, which can include a significant length of exposed flue. The combination of air heating, reduced excess air and considerable radiant output means these stoves can achieve efficiencies of 30% to 50%.

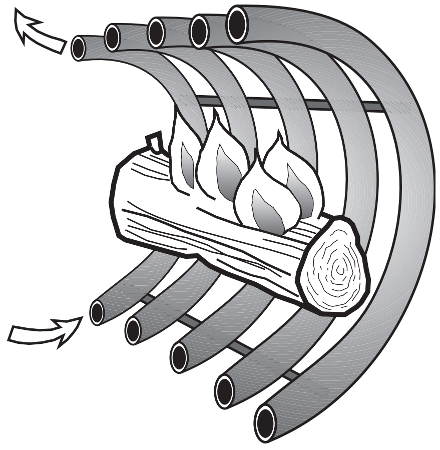


Figure 9.2: Tube grate (Ministry of Energy, 1983)

Controlled-combustion Heaters

In controlled-combustion heaters, the rate at which fuel burns is controlled by the amount of combustion air entering through an adjustable air inlet. When fully open, the fire will burn vigorously and as air is reduced, the rate of combustion will slow down, thus providing a good control of heat output.

These first generation controlled heaters operate most efficiently at medium to high burn rates; when the fire is hot and there is plenty of air to burn, all the combustible gases are released from the fuel. At slower rates, there can be some release of smoke and creosote.

Many designs have a baffled firebox, which helps mix flue gases, resulting in greater efficiency that can range, in a simple controlled combustion heater, from 30% to 60%. These heaters provide good, low-cost heating, provided they are well used and correctly sized for the heating need.

Figure 9.3 shows a range of enclosed heater configurations. Figure 9.3 (a) is a typical controlled baffle box heater. The last stove, Figure 9.3 (f), is a typical enclosed, but non-airtight, model. The other stoves are improved models, which are discussed below.

Improved Controlled-combustion Heaters

This group represents the mainstream of modern domestic heating appliances. Improved controlled-combustion heaters incorporate the basic designs of the above group but operate more efficiently at low burn rates.

These heaters usually have ceramic tile or vitreous enamel sides and are designed to be free standing units or fireplace inserts (inbuilt models). Most models rely on convective heat technology, although some have a fan forced capacity. All have reliable but complicated firebox design with baffles and secondary combustion chambers to ensure high efficiency and low emission levels.

Firebox technology offers a choice of ash grate or ash bed models constructed of cast steel or rolled welded steel materials, and are often firebrick lined for extra heat mass, durability and protection for the high temperatures achieved.

The firebox is surrounded by a cast or roll/welded steel outer case, which enables convective heat transfer either naturally or fan forced around the firebox to all parts of the room or home. These outer shieldings or casings, apart from boosting efficiency by convection, enable the appliance to be installed relatively close to combustible materials because of the lower outer case temperatures. This class of stove produces less radiant heat output but more air heating than Pot Belly stoves or most first generation controlled combustion appliances. Modern appliance design, high quality vitreous enamel or high temperature finishes, ease of operation and relative cost of heating make these appliances highly competitive with other forms of heating.

Stoves (b), (c) and (d) in Figure 9.3 show various designs of second generation controlled combustion stoves.

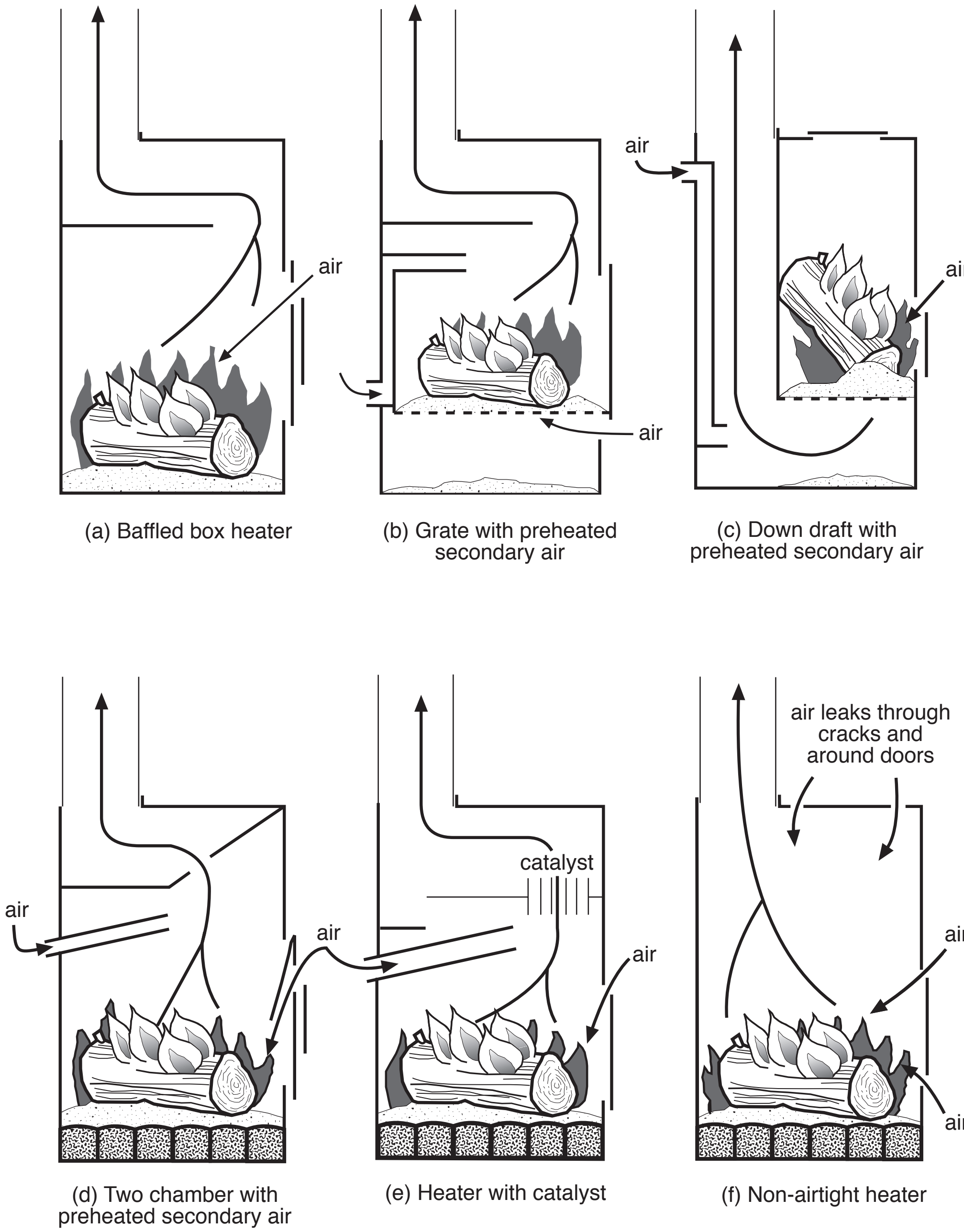


Figure 9.3: Some of the many types of combustion systems used in wood heaters (Wood, 1993)

Catalytic Heaters

Some wood heaters overseas incorporate catalysts such as platinum, which allow smoke and gaseous emissions from the fuel to burn at much lower temperatures. Stove (e) in Figure 9.3 shows a catalyst placed to facilitate better burning of the flue gases. This system means that cleaner, more efficient burning, is achieved at lower temperatures and with much less release of creosote. Tests indicate that catalysts can improve performance by up to 10%. However, these heaters have shortcomings.

With catalytic heaters, care must be taken not to burn plastics, rubbish or sometimes coal, which can drastically reduce the life of the catalyst.

Central Heating Systems

Fuelwood or coal is used in some central heating units. Boilers can be used to heat water to supply room radiators or concrete slab floor heating. Furnaces can be used to supply heated air for ducted heating systems.

Some domestic central heating firewood systems only have a single-charge system and require refuelling at least once a day. As mentioned earlier, more sophisticated automatic fuel supply systems are now available to use wood chips, wood chunks or coal. The down-draught combustion system shown in Figure 9.3 (c) lends itself well to automatic fuel supply systems. Fuel is dropped into the primary combustion zone from a hopper above. Central heating systems should be carefully sized to the heating load and have a wide performance band in order to maximise efficient operation.

Some systems overcome the need for automatic fuel supply and real-time load matching by having the stove attached to a heat store — invariably a well-insulated hot water tank. In a single burn the heater provides enough hot water for one to two days of space heating via a hydronic system (underfloor or radiators).

Control Mechanisms

Central heating systems with automatic fuel supply lend themselves to effective space heating control. Logic controllers and room sensors can be used to determine the required heat output.

Automatic controls for manually-fed, solid-fuel space heaters, the predominant form, are not readily available. Most householders respond to overheating by opening windows and doors (wasting heat) and shutting down the stove. If it is too cold, the stove air inlet is opened, more fuel inserted and/or an electric (or some other) heater is turned on temporarily.

Now that some heaters are able to obtain good efficiencies and low emissions across a range of heat outputs, it should be possible to thermostatically control the heaters by adjusting combustion air flows. An electronic control device linked to an appropriately located thermostat seems feasible. The development of such a system would enable better control of output, especially overheating.

9.4 Stove Installation

All wooden stoves should be installed in compliance with building codes and standards. The main aim of these regulations is to avoid fire risk and asphyxiation. Required wall clearance from stoves will depend on their design and level of radiant output. Flues need to be well isolated from combustible material where they pass through walls, ceilings and roofs. Adequate hearths are needed to protect the floor. In some areas, such as parts of Christchurch, emissions standards are in force. People intending to install solid fuel heaters should check this issue with their local authorities. From an energy efficiency point of view, the main installation issues are flue details and appliance location in the house.

Appliance Location

Most modern heaters are capable of putting out 10 to 15 kW, far more heat than a typical electrical appliance. To take advantage of this potential and to avoid overheating, solid fuel burners should be placed in large rooms, preferably centrally located so that heat can be allowed to spread throughout the house. Solid fuel heaters can work well with open plan design. In a multilevel home, placing the heater on the lowest floor will enable the use of convection to convey warm air to higher rooms. Floor ducts can be used to move warm air on from potential stratification pockets.

In many ways, the same principles apply as for solar space heating. Consideration should be given to using slow speed ceiling fans to uniformly mix room air, and ducting and return air fans to recycle warm air. Thermal mass in the building will help to even out comfort levels and dampen fluctuations in the stove's output when people forget to refuel adequately or set the burn level too high.

Flue Details

Modern heaters use relatively small diameter flues. The flue plays an important role in the operation of the heater. The hot air and gases created by fuel combustion expand and rise up the flue, creating a draught that pulls further air into the heater to support further combustion. Some of the air, or rather its oxygen content, is required for combustion. Additional or excess air is also drawn in to ensure the fuel does not "miss out" on oxygen and to ensure an adequate draught is created. The efficiency of modern heaters comes in part by minimising this excess air because heating it represents an energy loss (and it is often warm air from the room).

The downside of modern heaters is that the draught created by the flue is small and susceptible to a number of adverse factors, such as low, leaking or dirty flues, flues with bends and flues that enter roof pressure zones.

Low flues may not create enough draft. As a general rule, flues should be over 3.6 metres high. Bends restrict flue gas movement. Some stoves have the flue at the back to facilitate an exit through the wall behind. Flues from the top of the stove and straight through the roof are generally better. Leaks between flues joints may not be noticed, especially above the roofline, and they reduce the flue draught.

The build up of soot and creosote can reduce the effective diameter of a flue. Regular cleaning and heater operation to avoid creosote deposits are needed. Wind pressures created by roofs can affect a heater's operation — sometimes only when the wind is from one direction. The effect is usually subtle and is experienced as a form of downdraught (true downdraught can have several causes). Flues should terminate not less than 600 mm above a simple ridgeline or 1500 mm above a flat roof. Complex roof lines (e.g. sawtooth) may require special consideration.

9.5 Energy Efficiency Tests

Standards

New standards have been recently introduced in order to provide a uniform method of testing domestic solid fuel appliances for efficiency, and to specify an upper limit for particulate emission (NZS 7402, 1992; NZS 7403, 1992). These standards are:

- NZS 7402: 1992 Domestic solid fuel appliances — Method for determination of power output and efficiency.
- NZS 7403: 1992 Domestic solid fuel appliances — Method for determination of flue gas emission.

In 1992, a new facility for testing domestic heaters in accordance with these standards was designed, built and commissioned at Coal Research Ltd., Gracefield, Lower Hutt. The test facility consists of a calorimeter room built of polystyrene-filled panels 200 mm thick. It has a usable volume of 25.92 m^3 and is equipped with a double-glazed window to allow visual control of the test process.

The testing process is designed so that the heater is tested under conditions similar to those found in houses. To measure heat output, efficiency and emission levels, a fuel charge is calculated dependent on the heater firebox volume, loaded into the heater and burned on a 100 percent burndown basis. Testing is carried out at three burn rates (low, medium and high) and, for each regime, sufficient burn cycles (at least three) are performed until specified consistency criteria are met. Burn rates are altered by adjusting the heater air flow control.

During the test, a known amount of air is passed through the room and absorbs the heater's radiative and convective heat. The temperature of the incoming and outgoing air is measured and from this a heat balance and heater efficiency are calculated. The Standard does not specify minimum efficiency levels.

The smoke produced is discharged from the calorimeter room and captured by a dilution tunnel. A portion of diluted flue gas is sampled from the tunnel and particulates contained in this portion of flue gas are passed through and collected by glass fibre filters. The weight of particles retained on the filters is expressed in terms of grams per kilogram (g/kg) of dry fuel used. An appliance's Particulate Emission Factor is the average of these three burn rates. The standard sets a limit of 5.5 g per kg of dry fuel (NZS 7403, 1992).

Efficiency

The average burn time for 10 tested wood burning heaters (approximately 100 burn cycles) is 1 hour 3 minutes at high burn rate, 1 hour 39 minutes at medium burn rate and 2 hours 10 minutes for low burn rate. The average fuel charge is approximately 4.2 kg (3.4 to 3.5 kg dry basis,) giving a low burn rate of 1.55 to 1.63 kg/hr (dry basis). The relatively short burn times can be a disadvantage from the consumer's point of view; however, burn times can be extended to six to 10 hours at low burn rate by using a coal/wood mixtures (if the stove is a dual fuel design).

Space heating power output depends on the type of heater and the burn rate. For the heaters tested, it varied from 1.5 to 17 kW. Some heaters on the market have a power output of up to 25 kW.

Most of the heaters tested incorporated a water heating device or had provision for its installation. The water heating power output depends on the type of the device as well as the burnrate. For the heaters tested, it varied from 0.3 kW at low burn rate to 5.0 kW at high burn rate, but some heaters available on the market can produce as much as 10 to 12 kW.

The efficiencies of the heaters varied widely. All appliances tested could be divided into distinct groups of "higher" (group II) and "lower" (group I) efficiency heaters. The lower efficiency group consisted mainly of in-built heaters. The results of heater efficiency testing are shown in Figure 9.4.

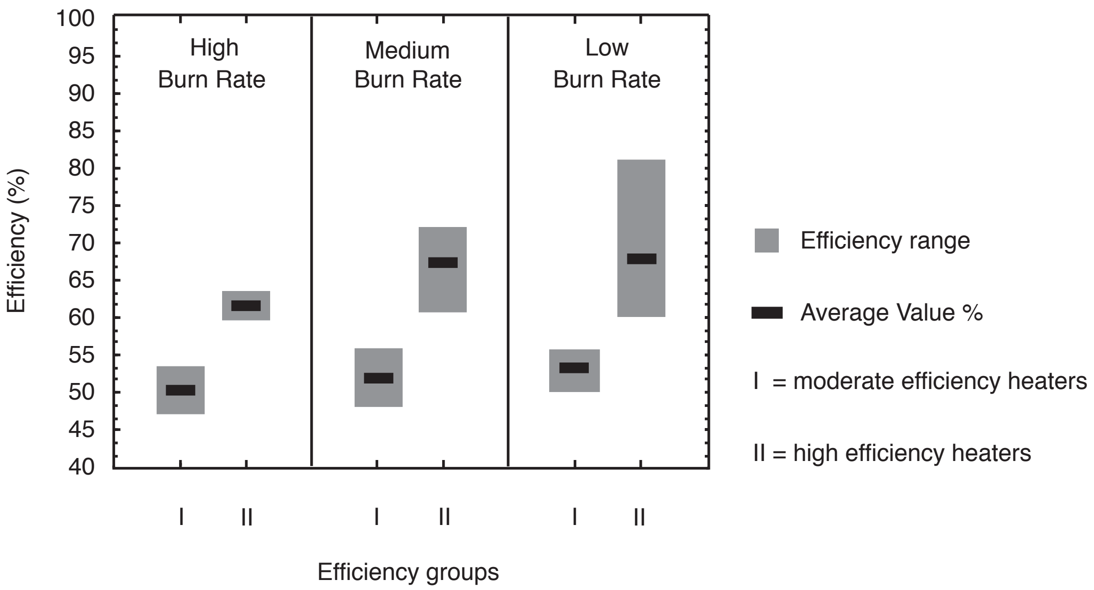


Figure 9.4: Overall efficiency distribution

These results indicate that:

- The efficiency for each burn rate varies widely. This is dependent on heater design only as the fuel parameters for this test are specified in the standard.
- The difference between the average efficiency for "lower" and "higher" groups varies from 50% to 62% at high burn rate, 54% to 67% at low burn rate and 52% to 68% at medium burn rates.
- At low burn rate, the difference between the average efficiency of all heaters and the best examples (with overall efficiency up to 80%) can reach 20%.
- The overall efficiency (both water heating power output and space heating power output) of most heaters can be substantially improved.

It is noteworthy that with modern heaters the low burn rate can be more efficient than high burn rates. The low burn rate is not likely to be slow enough for people who want to have the heater idle overnight. Over charging the heater and shutting down the air supply to obtain eight hour burn times could still lead to inefficient combustion and excessive emissions.

Emissions

In general, the highest emissions occur at the more efficient low burn rates. The same "high" and "low" categories for the heater test results were used for analysing emission data for high and low burn rates. Results of testing are shown in Figure 9.5.

The testing shows:

- The low burn rate has the highest impact on the appliance emission factor. A method has been developed whereby the low burn rate emission results can be used to estimate whether the appliance particulate emission factor (the average of the three burn rates) will be above or below 5.5 g/kg (*Consumer*, April 1993).

- All heaters tested emitting less than 8.0 to 8.5 g/kg at the low burn rate passed the test (i.e. the appliance overall emission factor was less than 5.5 g/kg).
- All heaters tested emitting more than 8.5 to 9.0 g/kg at the low burn rate emitted more than 4 g/kg at high fire and failed the test (i.e. the appliance emission factor was greater than 5.5 g/kg).

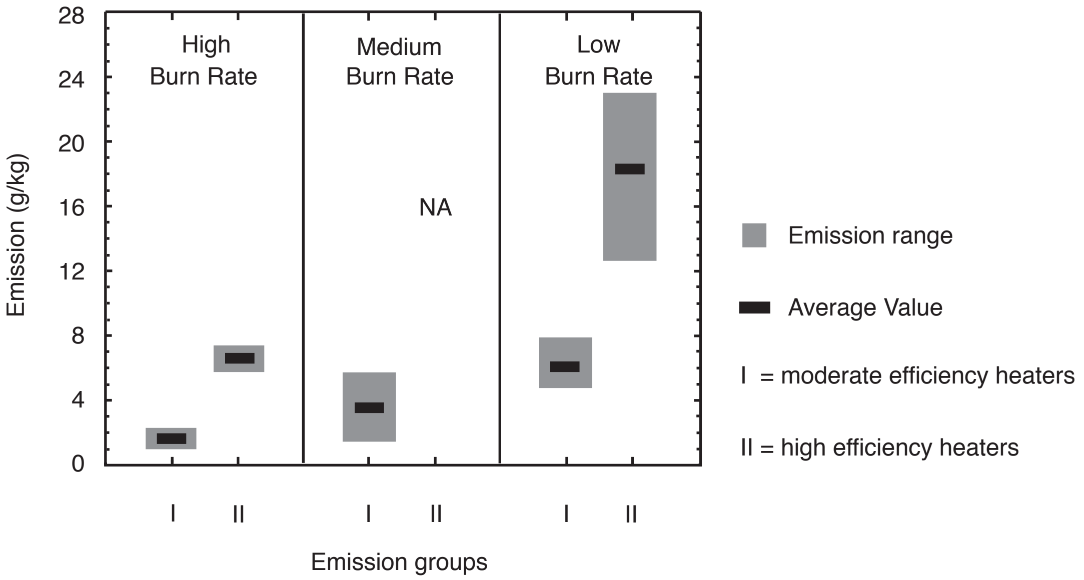


Figure 9.5: Particulate emission distribution

9.6 Conclusions

Potential for Improvement.

The efficiencies of enclosed heaters relate well to existing thermal electricity generation power stations of approximately 30% at point of use (or 40% for new combined cycle plant). However, taking into account the existing ratio of open fires to enclosed heaters, the present efficiency of solid fuels utilisation as a whole can be estimated as 38% to 40%. This estimation is based on the following assumptions:

- all open fires are still in operation and their efficiency can be estimated at approximately 20%; and
- the efficiency of enclosed solid fuel heaters can be estimated as the average for the high and low burn rates (50% and 62% respectively).

The two most effective ways of improving efficiency of solid fuel heating on a national basis would be to:

- Replace open fires with in-built heaters — approximately half of open fires could be gradually replaced with in-built heaters. The average efficiency of some good in-built heaters available on the market is 57% to 58% (50% at high burnrate and 65% at low burnrate).
- Improve enclosed heaters efficiency — the average efficiency of some well-designed heaters available on the market is as high as 66% (average of 60% at high burnrate and 72% at low burnrate). This efficiency figure is even higher for a number of the better models.

If the above scenario was adopted, the average efficiency of solid fuels utilisation across all households could reach 52%. The almost 30% efficiency rise for solid fuel consumption would mean a saving of around 2 PJ. This amount of energy is nearly equal to the total household's energy consumption for lighting (2.3 PJ) and is close to the energy consumption for cooking (3 PJ). This energy could be used for increasing the level of comfort in homes. At present, the average temperature during the winter time in New Zealand homes is only 16˚C (Isaacs, 1993).

There is a considerable variation in the efficiency of free-standing heaters at medium and low burn rates. Potential purchasers should ask for test results and compare these with the efficiency spreads shown in Figure 9.4 before making a choice. Of course, factors other than energy efficiency come into a purchasing decision. In a *Consumer* report, half the overall assessment score for woodburners was determined from efficiency performance (*Consumer*, 1992) and another 10% was given to the burners ability to operate on a low setting. Convenience and safety aspects made up the other 40% of the rating.

Positive Aspects of Solid Fuel Heating

- Prices of the energy sources. Recent surveys of the energy prices in the different regions have been conducted by *Consumer* magazine (*Consumer* , 1993). The results of this survey showed that:
  - The prices vary significantly in the different regions, increasing in urban areas (Wellington, Auckland).
  - The prices of solid fuels are close to prices of electricity and much lower than energy sources such as LPG.
  - The enclosed coal burners are competitive with electrical plug-in heating.
  - Wood burning enclosed heaters are competitive with electrical plug-in and night store heaters.
  - Low efficiency open fires are not competitive with any type of heating.
- The introduction of new standards has meant increased development for solid fuels heaters, resulting in efficiency increases and clean burning capabilities.
- Adoption of more widespread solid fuel heating would lessen requirements for future electrical power generation stations. This also has the benefit of the population not being so dependent on large, centralised plants.
- Resources are generally more efficiently used by direct conversion to useful energy via solid fuel heaters than by conversion to secondary forms of energy.
- Solid fuels utilise renewable forms of energy, such as wood, or abundant forms of energy, such as coal.

Negative Aspects and Barriers

- The cost of testing to a standard may mean manufacturers will be content to rest on their laurels once the standard has been reached rather than alter the stove and face the prospect of re-testing.
- Efficiencies are not yet a consideration in the purchaser’s mind, as most stoves are still sold on the basis of their output and aesthetic appeal.
- The adoption of minimum standards is desirable to avoid localised “nuisance value” emission impacts and adverse reaction to more widespread adoption of solid fuel heating.
- At present, there is little widespread information about the detailed methods of heater design to maximise efficiency and reduce emissions across a range of burner rates.

References

Department of Statistics (1992). *Household expenditure and Income Survey, 1992.*

Consumers Institute (1992). “Test — woodburners”, *Consumer*, No 303, April, 1992.

Consumers Institute (1993). “The cheapest fuels”, *Consumer*, No 313, April, 1993.

Isaacs, N (1993). *Thermal Efficiency in New Zealand Buildings*, Centre for Building Performance Research. Victoria University of Wellington.

Korolev, V, N G Purchase and A H Clemens (1993). "Solid fuel combustion studies at Coal Research for residential and industrial applications", *Fifth New Zealand Coal Conference*, 1993, Wellington.

Ministry of Energy (1983). *How to Heat Your Home*, Ministry of Energy and Asia Pacific Economic News, Wellington.

NZS 7402:1992. *Domestic Solid Fuel Appliances — Method for Determination of Power Output and Efficiency*.

NZS 7403: 1992. *Domestic Solid Fuel Appliances — Method for Determination of Flue Gas Emission*.

Resource Management Act (1991). New Zealand Government Printer, Wellington.

Wood, K (1993). "Woodburners in Australia" in *The Australian Renewable Energy Industry*, pub. Department of Primary Industries and Energy, Canberra.

Chapter 10
Natural Gas Heating

This chapter outlines the range of natural gas space heating appliances available. It identifies the two main features of energy efficient appliances — good control and maximum heat recovery. The technological innovations that contribute to efficient appliances are discussed and are illustrated by reference to appliances on the market in New Zealand. The chapter ends with a short note on advanced technologies that might find their way into homes within ten years. This chapter should be read in conjunction with Chapter 7, which sets out general principles of space heating and provides an overview of this subject. The latter part of Chapter 8 deals with controls for electric heating and this is generally applicable to gas heating as well. Natural gas water heating is covered in Chapter 11, "Domestic Water Heating".

10.1 Natural Gas Appliances

Natural gas appliances can be portable or fixed, radiant or convective (air heaters), room based, or part of a central heating unit. Since natural gas is clean burning and does not produce smoke, gas appliances can also be unflued as well as flued. Unflued heaters are very efficient in that all the heat of combustion is placed into the room. On the other hand, as mentioned in Chapter 7, the flue gases add to indoor pollution and extra room ventilation is needed. The extra ventilation means that unflued appliance efficiency is usually quoted as 90%.

Flueless Heaters

Portable heaters are flueless. Some fixed heaters may also be flueless. Portable heaters are mainly radiant and can have heat outputs of up to 4.2 kW. They are installed on a flexible connection up to two metres long, which can be plugged into a floor-mounted bayonet socket. Typical flueless radiant heaters produce about half the energy output as radiant heat, the rest as warm air. The most common combustion system involves a gas/air mixture passing through tiny holes in a ceramic plate and burning at the surface. Radiant heat is given off from both the flames and the glowing ceramic.

Flueless convection heaters range in output from 2 to 4.5 kW. The air flow is usually drawn through the heater by natural convection, but some models have fans. They are suitable for providing background heat, whereas the flueless radiant heaters are more suitable where rapid and direct heating of people is required.

Simple Flued Heaters

This class of heaters take their combustion air from the installation room but remove the flue gases from the room. They avoid the indoor air quality issue, but a significant amount of heat can be lost in the flue gases. They can also cause draughts when in standby mode (see Section 10.2). Their efficiency can range from 50% to 75%, depending on the degree of heat recovery from the flue gases. These units operate so that water vapour in the flue gases does not condense — the latent heat of evaporation is therefore still lost.

Flued radiant convector heaters range from 3.5 to 7 kW. About one-third of their heat output is from radiant heat and the rest as heated air. The radiant heat can come off a ceramic combustion surface or at a lower temperature from an enclosed combustion chamber with a radiant panel. Either way, the appliances radiate heat to people and objects nearby. The combustion products pass through a heat exchanger, which heats room air, before going out the flue. Flued convector heaters do not have radiant panels and are designed to distribute all their available heat as warm air. Both types of heater can have convector fans.

Balanced Flue Heaters

As well as having flues, heaters of this type obtain combustion air from outside the room. This reduces the effect of induced draughts during heater standby and, depending on the level of heat recovery from the flue gases, the efficiency of these heaters can range from 50% to 80%.

Simple flued heaters can be designed with the flue passing through a roof or horizontally through a wall. Balanced flue heaters are designed to have the flue pass through a wall and consequently need to be installed on an outside wall. Some designs have the air intake and flue combined into a single unit so that only one hole is needed. This reduces installation costs, flashing requirements, etc.

Flame Effect Fires

A range of appliances that feature the gas flame are available. The flame can be used as one of a set of props intended to mimic the appearance of a wood and coal burner. Alternatively, the flame can be placed and feature alone in a unit with a contemporary design. Some models are designed to be installed in existing fireplaces while others are freestanding. These appliances usually operate as flued radiant convectors. They can be as efficient as other gas heaters when provided with a heat exchanger that recovers the flue gas heat to the limit beyond which condensation occurs.

Controls on Appliances

The level of controls on gas appliances is usually a function of heater size and cost. Small heaters usually only have a limited number of heat settings. The next step is thermostatic controls on the heater. Very few, if any, room-based gas heaters available in New Zealand have remote thermostats. The larger and more expensive appliances have timer controls. The simplest are once a day on-off controls. The better appliances have three or four time settings and allow different temperature targets for each time period. As strongly emphasised in earlier chapters, good control is essential if the temperature levels needed for a healthy home environment are to be achieved in an energy-efficient manner.

Wall Furnaces and Central Heating

Wall furnaces are large-scale wall-mounted flued convector heaters with outputs of up to 7 kW. They can be designed to draw air from outside the house (underfloor). They can also be designed to heat the two rooms either side of the wall the heater is placed on.

Gas-fired central heating can provide ducted warm air to all rooms of a home. Return air is drawn from a centrally located grille and directed back to the heater for rewarming. A well-designed system can provide even all round warmth with no cold spots. Ceiling diffusers or floor-mounted registers can control air floor to individual rooms. Electronic energy management, timer control and thermostat systems control warm air flows, temperature, timing of warm air delivery, fresh air inflow etc. A regular daily schedule with a special weekend programme can be set. Different temperature targets can be achieved at different times of the day and for different parts of the house.

A wide range of models are available. The most efficient wall furnaces and central heating systems use condensing flues. This technology is explained further in the next two sections. Essentially, most of the heat in the flue gasses, including the latent heat in the flue gas water vapour, is recovered. This, together with other features, means that efficiencies of up to 90% can be achieved.

Another consequence of using condensing flue technology is that the flue gases end up cool to touch. Materials such as UPVC can be used as flues. This greatly simplifies installation (a condensate drain is needed though) and provides considerable flexibility for heater placement as well. Figure 10.1 shows a typical underfloor installation. A heater can be mounted under a home, outside or in roof space, with either underfloor or ceiling ducting. Natural gas can also be used to provide hot water for hydronic central heating systems (refer to Section 7.6 for a description of hydronic systems).

10.2 Efficient Gas Heating Technologies

This section reviews the development of high efficiency natural gas heating appliances and outlines the main technological innovations.

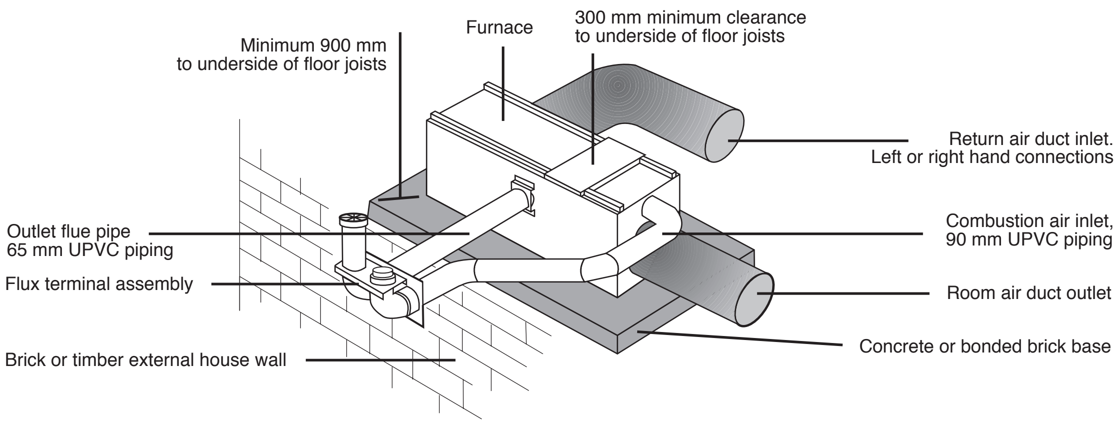


Figure 10.1: Underfloor central heating furnace: typical installation for condensing flue unit (refer to individual manufacturer's installation specifications)

Energy Loss from Appliances

A significant amount of heat is lost in conventional natural gas air and water heaters. Four major causes can be distinguished, the first, and most important being the temperature of flue gases. Traditional gas appliances use natural draught to discharge the products of combustion. This means that the flue gasses have to leave the appliance at a relatively high temperature in order to maintain an adequate air intake. Consequently, any unused heat escapes.

Loss of warm room air is the second cause of energy loss. Appliances that take their combustion and excess air from living areas draw warm air from the space they are trying to heat.

Standby air losses are also an important cause of low efficiency. Even when not operating warm air can be lost from the room connected to a heater. In standby mode, heat can be transferred from the appliance's heat exchanger back to the air in the combustion zone, causing an internal draught. Air is drawn from the installation room into the appliance and lost through the flue.

This problem does not occur when the combustion air is drawn from outside the room. Balanced flue convection heaters with large heat exchangers could, however, transfer some room heat through the exchanger to the combustion chamber, and induce a draft to take this heat away.

Radiation and convection losses are another source of inefficiencies. Appliances with poorly insulated housings lose substantial quantities of heat to their surroundings. This may not be an issue for a space heater fully located within a room, but it is a major problem for basement of external central heating units, hot water heaters, etc.

Having a pilot flame on all the time is a direct energy loss, albeit usually small —perhaps 4 to 5 GJ per year. Another possible cause of energy loss, which mainly applies to modern equipment with forced air systems, is inefficient electric motor drives and fans.

Evolution of Efficient Appliances

Gas-fired appliances roughly split into three efficiency categories according to the amount of energy they lose in their flue gas emissions. The first category comprises all conventional appliances: their traditional construction results in a modest annual in-use efficiency of around 50%. The second category consists of so-called improved efficiency appliances: these recover just enough heat from the flue gases to avoid condensation of the water vapour produced during combustion. They are often called "nearly condensing appliances" for that reason. The annual in-use efficiency of these appliances is around 70%. The third category is the higher efficiency category consisting of fully condensing appliances. They feature annual in-use efficiencies of 85% or more.

In parallel with improvements in flue gas energy recovery there have been a number of other advances. The main ones have been:

- fan forced combustion and increased heat exchanger area;
- elimination of combustion and excess air losses;
- reduced standby losses from draughts and pilot flames;
- better appliance insulation;
- improved control of air to gas ratios; and
- more efficient electric motors and fans.

Development of Condensing Gas Appliances

Only in the last 10 to 15 years has the shift from conventional to high efficiency appliances taken place in Europe and North America, where domestic space heating requirements are high. The motivation has been energy efficiency and low pollution objectives. This evolution may be sketched in broad outline using condensing appliances as an example.

Prompted by the energy crises of the 1970s, considerable efforts were made during the next few years to improve the efficiency of gas appliances. The first generation of condensing appliances was developed to deal with the major source of inefficiency, namely flue gas heat loss. The key feature of these appliances is a secondary as well as a primary heat exchanger.

The appliances incorporate a fan to assist transport of the flue gases. A fan is needed because the increased heat exchanger surface cools the flue gases to temperatures at which the thermal draught is insufficient to guarantee the transport of combustion air and flue under all circumstances.

The flue gases are cooled by the primary heat exchanger to about 150˚C. The secondary heat exchanger provides further cooling to temperatures below dew point, thus causing the water vapour contained in the flue gases to condense. A drain is needed for the condensate. As the condensate can be mildly acidic, corrosion-resistant materials must be used in the secondary heat exchanger and condensate drainage systems.

As mentioned in Section 10.1, the flue gases can be cooled to the point where PVC flues can be used and flue isolation from flammable materials is not an issue. This increases the options for appliance location.

First generation condensing appliances are generally better insulated than conventional appliances and they often feature electronic ignition instead of pilot ignition.

Second generation appliances are of the room-sealed type, i.e. the combustion air is not drawn from the installation room but directly from the outdoors. This type of construction has a number of advantages. First, the appliance is totally independent of the indoor climate, so there is no need for special ventilation requirements to the installation room. Moreover, when the appliance is not operating, the internal draught and, hence, standby losses are moderated by the higher internal resistance inherent in the design of this type of appliance.

Again, a fan is needed to ensure the necessary transport of combustion air and flue gases. In contrast to the first generation, however, second generation high-efficiency appliances often have their fan fitted in the combustion air supply line rather than in the combustion products flow. In this position, the fan's service life is longer with the additional advantage of improved accuracy in controlling the air rate.

Another aspect closely related to an appliance's overall efficiency is its power consumption. It is expected that electric power consumption in gas appliances will in future be included in efficiency determinations. In anticipation, efforts are being made to minimise power consumption of fans, blowers and pumps.

Combustion Improvements

Second generation condensing appliances feature fully premixed burners, which reduce the flame length, thus allowing for more compact and, therefore, cheaper appliances. Of course, much attention is being paid to thermal insulation on these appliances, which also feature electronic ignition systems.

A recent development is gas appliances that incorporate so-called gas-air ratio control. In the past, full-load efficiency was emphasised, but it is expected that part-load efficiencies will be increasingly important. Actually, the majority of heating equipment operating hours are used to cover heat demands smaller than 20% of full load. The efficiency under reduced load conditions will, therefore, largely decide an installation's overall energy efficiency.

Appliances fitted with gas-air ratio control (either pneumatic or using an oxygen sensor) comply with this principle. They are characterised by optimum combustion and high efficiency at any output level. Output can be modulated to provide very uniform room temperatures (refer to Figure 8.14 and the related text).

Marketing Issues

Conventional, improved (near condensing) and high efficiency (condensing) appliance categories are not separately recognised or marketed in all countries. Although many countries take an active interest in high efficiency appliances, the real growth markets are France, the Netherlands, the UK (especially for central heating boilers) and the US (mainly for warm air central heating).

Improved efficiency central heating boilers are popular in France, Belgium, Denmark, the Netherlands, Italy and Spain. In the US, improved efficiency appliances for warm air central heating are more popular.

In New Zealand, some natural gas central heating unit manufacturers market condensing equipment as "high efficiency" appliances and this may raise awareness of efficiency issues.

The market share of improved and high efficiency gas appliances can be advanced in several ways: the US, the UK and the Netherlands grant subsidies to those who purchase these appliances, and in Austria consumers are offered free advice.

Some countries have created special quality marks for condensing appliances and this makes the selection process easier for consumers. On the regulatory side, there are opportunities for promotion as well, e.g. French and Danish consumers have virtually no choice but to purchase improved or high efficiency appliances. Conversely, regulations may also pose an impediment to further penetration of the market by these appliances. Overly cautious requirements relating to the discharge of condensate and flue gas discharge systems are cases in point.

10.3 Condensing Appliance Case Study

This section describes the costs, benefits and features of energy efficient natural gas central heating. At least three different major furnace makes are available in New Zealand and each manufacturer offers improved, as well high efficiency, condensing furnaces.

Converting to central heating may (but not always) mean using more consumer energy for many New Zealand households because it presents the opportunity to effectively heat all rooms. Compared with achieving the same level of amenity with heaters in every room, gas central heating is likely to be a more energy efficient and cost effective solution. There are two reasons for this. Firstly, the extra cost of buying a very efficient condensing furnace (around 90% efficient) rather than a conventional unit or series of conventional room-based gas heaters is small. Secondly, given the scale of the investment, the extra cost of also investing in a sophisticated energy management and timer/temperature control systems is also small.

The basic cost of a central heating system for a typical home is around \$5000. This will cover the furnace, a basic programmer, ducting and six warm air outlets, a return air duct and system installation. An energy management system (\$250) and zone controller (\$200) would only add another \$450, or less than 10%.

Control Systems

The basic programmers or timers turn the furnace on or off in accordance with preset times or temperature targets monitored by a carefully located main thermostat. The more sophisticated timer systems allow different temperature targets to be set for different times of the day. If the house is above the target, due to passive solar gain say, then the furnace will not come on. Zone control, lower temperatures in bedrooms for example, is usually achieved by manually shutting room registers or using thermostatically controlled dampers. Reducing the load on the system in this way could cause it to switch on and off more frequently resulting in fluctuating airflows. Energy management systems can avoid this.

Energy management systems allow the furnace output to be modulated. Manual or automatic adjustment of room registers to alter room temperature from the general target will cause a shift in system back pressure. This is detected by the energy management system and the furnace output is finely adjusted (rather than turned off) to deal with the reduced load. Furnaces suitable for modulation are designed to run efficiently at part loads.

Warm air central heating has two delivery variables to achieve its temperature targets; air flow rate and temperature. At commissioning, most systems are set up to deliver air at a constant temperature for a given thermostat target. If modulation takes place due a shift in load, either from shutting down a zone or higher outside temperatures, then the furnace output and delivery fan power is adjusted so that the temperature of air coming out of the registers does not change.

Furnace Hardware

Figure 10.2 shows a schematic for a Brivis high efficiency furnace. The key energy efficiency features of this unit are outlined below. This furnace has most of the efficiency features of second generation plant identified in Section 10.2. Efficient gas combustion (2) with controlled air to gas ratios takes place in thin chambers (1). Air drawn from within the house is blown over a bank of these chambers and is warmed before returning to the house (4). The large surface area of the chambers, enhanced with dimples, makes for efficient heat exchange.

Instead of simply expelling the flue gases, a fan (8) draws them down through a second heat exchanger (9). This second heat exchanger, which looks something like the radiator on a car, extracts the remaining available heat from the flue gases. This heat is passed to the return air stream before it enters the primary heat exchanger bank.

The flue gases are now only warm to touch (7). With some makes and models, the final part of the flue can be UPVC.

Condensation flows to a sump and is then drained from the system (5). The unit is insulated with a heat resistant polyester lining (6). The furnace cabinet is made of weather-resistant Colourbond steel.

The Vulcan central heating furnace has a similar combustion system to the Brivis unit. Lennox gas furnaces, however use quite a different pulse combustion system. This system uses self-sustaining intermittent firing with 60 to 70 heating cycles per minute. The combustion systems creates a high level of turbulence, which assists with efficient heat exchange. A secondary condensing heat exchanger adds to the efficiency.

Pulse combustion starts with an air-gas mixture entering the combustion chamber and being ignited by an electric spark. Combustion is akin to that which takes place in a motor engine cylinder head. Internal pressure relieves itself by forcing combustion products down a tailpipe and through the heat exchangers. As the combustion chamber empties, it creates a vacuum that draws in the next gas air charge. At the same time, a back pressure pulse is reflected from the end of the tailpipe. This pulse of hot gases enters the combustion chamber, ignites the new charge and the process is then repeated.

10.4 Advanced Natural Gas Technologies

In addition to the direct combustion space heating and hot water heating appliances discussed above, there are other kinds of high-efficiency gas appliances such as natural gas engine driven heat pumps, small-scale cogeneration (CHP) units or thermionic energy converters (an illustration and discussion of a gas engine heat pump is provided in Volume 2, Part 8, “General Energy Efficiency Technologies”, Section 3.1). Although sufficiently mature and capable of high efficiency levels, these technologies have failed to find widespread application in the domestic sector so far.

Obviously, the commercial success of these concepts will in the long term primarily depend on their cost-effectiveness, with energy prices as a predominant element.

Gas-fired absorption refrigeration systems are an established technology for providing the air conditioning (heat and cooling) requirements of commercial buildings. A development programme in Japan has resulted in the production of prototype domestic absorption heating/cooling systems in the 2.2 to 7 kW range by a number of manufacturers. These units, comparable in size to their electrical counterparts, are expected to be commercially available before the end of the century. A description of absorption heat pump and transformer technology is provided in Volume 2, Part 8, “General Energy Efficiency Technologies”, Section 3.3.

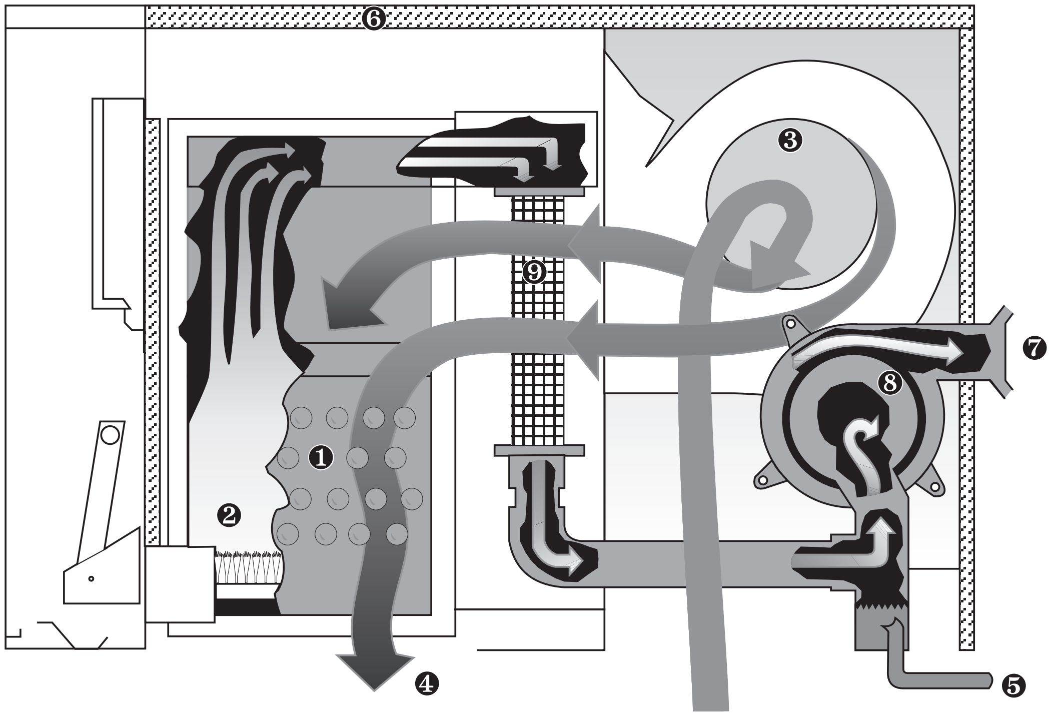


Figure 10.2: Schematic of condensing central heating furnace (Source: Brivis brochure)

Chapter 11
Domestic Water Heating

The first part of this chapter provides an overview of water heating systems used in New Zealand and discusses the potential for improved energy efficiency. The barriers to achieving more energy efficient water heating are reviewed.

Section 11.2 outlines the main factors that need to be considered in the design, installation and operation of a water heating system to achieve energy efficiency. The interaction of factors is illustrated by reference to an electric storage cylinder system. Electric water heating with conventional cylinders and electric elements is discussed further in Section 11.3. The importance of built-in insulation or retrofitting cylinder wraps is emphasised. With careful cylinder and system design conventional electric systems could be 30% or more efficient than at present.

Sections 11.4 to 11.6 are devoted to describing new technologies that also have the potential to greatly improve water heating efficiency. Examples of electric, solid fuel and natural gas innovations are described. The first example is an electric heat pump system with the potential for solar enhancement. This is described in Section 11.4.

There is mixed experience in New Zealand with water heating using wetback systems on solid fuel heaters. A new development that enables efficient and effective use of woodburners for space and water heating is described in Section 11.5. Natural gas can provide efficient water heating. The key features of a very efficient instantaneous system are outlined in Section 11.6. Solar water heating is a large topic in its own right. This form of water heating is covered in Chapter 12.

11.1 Introduction

There are around 1.5 million water heating systems in New Zealand of which about 1.2 million are in houses. The balance are residential-scale (less than 500 litres) water heating units in commercial and industrial installations. Many commercial installations have cylinders located in washroom areas, some hotels and motels have installations in each accommodation unit and factories have cylinders located in numerous places.

Approximately 14% of the country's total energy use and 35% of electricity use occurs in homes. Much of this energy, approximately 40%, is used to heat water.

Current Situation

Residential water heating systems in New Zealand are generally not very energy efficient. The dominant form of water heating is the conventional cylinder with electric resistance elements. Up to 30% of the energy input to cylinders escapes as standing losses. Only 5% of existing electric water storage heaters meet the WaterMark "A" Grade insulation standard (Section 11.3). Over 750,000 residential units do not even meet the "B" Grade insulation standard. There is clearly room for substantial improvement.

Energy efficiency in providing hot water services extends beyond the issue of just heating and storing water. It also depends on consumption levels and patterns, and total system design. Some aspects of consumption, such as cold water clothes washing and low flow shower heads, have received attention recently. The importance of wider system design, however, has tended to be overlooked. This issue is covered in Section 11.2.

Water Heater Market

Any strategy for improving the efficiency of water heating and storage has to take into account the normal lifetime and turnover of water heating appliances. The typical life expectancy for the main types of heating appliances is:

- 25 to 30 years for low-pressure electric units;
- approximately 20 years for gas-fuelled appliances;
- around 10 to 12 years for electric mains-pressure units.

Each year, old stock is replaced and the total number of units expands slightly due to new housing. The total annual market for water heaters is of the order of 70,000 units. Approximately 10% of these are gas fuelled. The approximate market breakdown is thought to be:

- electric storage units (45,000 low pressure and 20,000 mains pressure per year);
- instantaneous electric heaters (around 1000 per year);
- natural gas and LPG storage units (about 5000 per year);
- instantaneous gas and LPG units (1000 per year); and
- solid fuel wetback, solar and electric heat pump (perhaps 1000).

Wetbacks and solar units usually have a backup heating system, often electric. Electric storage heaters usually fall into three power demand categories:

- controlled off-peak (power available 16 hours or more per day);
- night rate (power only available at night typically 11 pm to 7 am); and
- continuous (power available 24 hours each day).

Potential for Improvements

The efficiency gains to be made in hot water systems can be easily identified in general terms, but it is more difficult to quantify them and it is impossible to state categorically that the improvement in efficiency will translate into reduced electricity demand in direct proportion. This is because a considerable number of systems currently installed (estimated at over 60%) are at some time unable to deliver the customer's needs. Therefore, improvements in efficiency may also be taken out in improved service ("clawback") rather than energy savings.

Mindful of this caution, it has been estimated that doubling the number of "A" Grade water cylinders to 10% of the total would reduce water heating energy demand by 300 GWh per year. A recent study (Henderson, 1994) estimated that improved water heating systems (cylinder insulation, wraps, tempering valves, pipe insulation etc) in around 90% of homes would result in energy savings of at least 600 GWh per year. While there may be some savings clawback, the potential for energy efficiency is very large.

Barriers to Improvement

To improve hot water heating efficiency an integrated strategy that addresses the main barriers to improvement is required. Barriers exist at each point in the manufacturing, trade and consumer continuum.

Hot water cylinders have a long life. A number of inefficient cylinders are recycled from one installation to another, with the main criteria being that they still hold water.

When a hot water cylinder does fail, consumers often leave decisions on replacement to plumbers. The plumbing fraternity has traditionally had a low level of interest in the efficiency of hot water systems (the EECA programme mentioned shortly may change this). The motivation for plumbers is ensuring the lowest possible cost of the installation commensurate with a system that will be accepted by the customer. Technology advances over recent years have been slow in the uptake because of the natural inclination of the trade to stay with traditional practices.

Home builders focus on reducing up-front rather than life-cycle costs. Building code requirements ensure a minimum standard of building envelope insulation, but there are no statutory minimum energy performance standards (MEPS) for hot water systems (refer to Chapter 14 for more information on MEPS). The New Zealand Standards for hot water cylinder thermal performance are not mandatory.

Manufacturers aim to satisfy householder and plumber/builder demands for low up-front costs. There is a market for cheap but inefficient water cylinders. Respect for consumer sovereignty is not the full story, however. Some manufacturers do not appreciate the importance of energy efficiency and lifecycle costs, or do not care, and are not taking a share of the responsibility to educate the market.

The Electricity Supply Association has promoted the WaterMark labelling scheme for electric water cylinders, but progress in getting all cylinders labelled and increasing the market share of “A” grade cylinders is slow. Power companies could assist here by promoting efficient cylinders and choosing not to stock unlabelled or low grade cylinders, but few do.

EECA has developed a hot water programme for introduction in 1995/96, which will attempt to address these barriers and bring together manufacturers, the trades, consumers and power companies in a cooperative venture. This joint venture may reduce the barriers noted above

11.2 Hot Water System Design

Installation improvements to raise the efficiency of hot water systems requires a total system approach and design and selection of the appropriate components. The correct installation of the plumbing system is critical to the satisfactory performance of the system and the efficiency of the whole installation.

Areas where energy efficiency can be improved include:

- efficient heat input to the hot water;
- superior thermal insulation of storage cylinder;
- use of instantaneous heaters to avoid standing and pipe losses;
- insulation of delivery system with high quality materials;
- down-sizing of pipes to reduce volume left in pipes while still maintaining delivery pressure under maximum demand;
- optimising pipes runs to reduce length and maximise efficiency;
- careful selection of valves and flow restrictors for system;
- circuitry design to avoid backflow (wetbacks and solar systems);
- cold water rather than hot water valve venting of pressure systems;
- three-port mixing or tempering valves for safety and energy efficiency;
- correct selection of energy-efficient major end-use appliances e.g. washing machine and dishwasher;
- selection of shower rose for both performance and efficiency;
- use of cold water whenever possible, e.g. ambient to 20˚C water for clothes washing;
- installation of control thermostat to meet NZS:6214 1988; and
- matching of taps and fittings to the pressure of the system.

The gains in overall efficiency that are possible in a correctly designed, efficient and good performance system exceeds 30% of the energy that is used in a typical domestic electric hot water system.

Component Interaction

The interaction of components for an electric system can be illustrated by considering cylinder size, temperature setting, the use of tempering valves and a common end use, such as showering. Except for lukewarm clothes washing, most household use requires a mix of hot and cold water, resulting in a temperature of at least 40˚C. The capacity of a system can be taken as the amount of water it can provide above 40˚C, after mixing the hot water with ambient cold water.

Many hot water cylinder thermostats are set to 65˚C or higher, whereas a temperature at the tap of around 50˚C to 55˚C is safe and meets the maximum temperature requirements for household use. Lowering the cylinder temperature from 65˚C to 55˚C will reduce the cylinder standing heat loss by 20%, but will also reduce the effective capacity by 40%.

Many water cylinders are undersized in that they could not meet household requirements if set to 55˚C Maximum system demand (litres per hour) is typically twice the average demand. Factors such as increased numbers in the home, successive loads of washing and lower incoming water temperatures (in winter) all impact on maximum demands. Houses change hands and family sizes vary. The most common way to accommodate these factors is to adjust the cylinder thermostat.

When cylinder grade and water-use patterns are considered, lowering the temperature may not be worthwhile. Expressed as a percentage of total consumption, the heat loss of a WaterMark A grade cylinder is theoretically between 12.5% and 15% of total consumption. Therefore, reducing the temperature from 65˚C to 55˚C will, theoretically, achieve a 3% improvement in overall energy consumption. There are easier ways of saving this much energy.

Cylinder and Fittings

It should first be noted that having a well-insulated cylinder is more important than lowering the water temperature. The cylinder should be WaterMark "A" grade or higher, or it should be wrapped in extra insulation (see Section 11.4). The other main factors in an efficient system are:

- fitting the cylinder with a consumer-adjustable thermostat so that it can be operated at the lowest possible temperature commensurate with a satisfactory performance (capacity);
- fitting a tempering valve to maintain delivery temperature below the temperature of the water stored in the cylinder;
- using an efficient cylinder venting system;
- insulating all pipes and valves that stay hot or are used a lot; and
- fitting efficient end-use equipment and appliances.

A tempering valve working at 50˚C will reduce pipe losses by up to 25% and reduce hot water consumption by appliances with coarse temperature selection, such as washing machines, by 15%. It will also mean that the potential for scalding is avoided. The use of pressure relief valves and venting systems is discussed shortly.

The main use of hot water in most households is for showers. Many shower heads put out 12 to 16 litres per minute. An efficient shower head may only use 7 to 8 litres. Some people may experience a slight loss of amenity at this flow rate. In such cases, even if the flow rate was only cut back to 8 to 10 litres, a hot water saving for this use alone could be 25% to 30%.

Instantaneous natural gas water heaters sidestep the issue of storage losses and volume capacity. They have inbuilt tempering features, and some are able to deliver different water temperatures for different end uses; showers versus dishwashing in the kitchen, for example. One such system is described in Section 11.6.

Venting and Pressure Relief

Hot water cylinders require a means to relieve temperature and pressure buildup due to water expansion, failure of the thermostat etc. The attachments used to achieve this can be sources of energy loss. Low pressure systems usually have an open vent pipe from the top of the cylinder. This typically discharges onto the house roof (see Figure 11.7 (a)), although in some cases the discharge can be back into the header tank, where one exists (see Figure 11.7 (b)). Neither approach will be energy efficient unless the whole vent pipe is well insulated. This is because even when the vent is not discharging, thermal circulation currents will exist in the pipe, taking heat from the cylinder and radiating it from the vent pipe.

An alternative to insulating the whole vent pipe is to fit a heat trap. A heat trap is a full loop or downward U bend in the vent pipe that cuts off the thermal circulation. Water above the trap will remain cold. The vent pipe leading up to the heat trap should be insulated.

Some low-pressure systems do not use an open vent pipe, but have a pressure relief valve instead. If this relief valve is at the top of a tall vent pipe, then again good insulation is essential. The best place for the relief valve is right beside the cylinder. Converting open-vented systems to relief valve systems improves energy efficiency and increases water pressure.

Mains pressure systems have a temperature and pressure relief valve at the top of the cylinder. As water is heated it expands and some of it — around 3% to 4% of the water heated — is lost. A cold-water expansion valve attached to the cylinder supply line avoids this loss. The use of line filters is recommended. By filtering out grit these reduce the risk of valves and taps not closing properly and reduce tap seat wear. Dripping taps and valves can be important causes of energy loss. More information on improving the energy efficiency and performance of hot water systems is available in a booklet from EECA (EECA, 1995).

11.3 Conventional Hot Water Cylinders

The importance of adequate insulation for hot water storage cylinders was discussed in Section 11.2. This section looks more closely at the insulation of new and existing electric hot water cylinders.

Cylinder Design: WaterMark Scheme

Electric elements installed in the hot water storage vessel are the most common method used for heating water. The input of energy is deemed to be 100% efficient; however, the percentage of this energy input available as hot water from the cylinder depends on the effectiveness of the thermal insulation and the volume of water used per day.

The effectiveness of the thermal insulation around hot water cylinders has improved significantly over the last 40 years as cylinders have been insulated to meet the increasing requirements of New Zealand Standards. A number of manufacturers adopted expanded foaming insulation techniques from 1985 and, as a result, the thermal insulation of cylinders improved above the requirements of the New Zealand Standard in force at that time. Some manufacturers took the opportunity to reduce the thickness of insulation, taking advantage of increased performance of expanded foam to reduce the cost of materials.

To improve the thermal performance of electric hot water cylinders, the Electrical Development Association introduced the WaterMark system. Under this scheme, manufacturers can be licensed to place a proprietary label on hot water cylinders. The label, shown in Figure 11.1, has three parts. It consists of the registered WaterMark symbol, a grade label and a recommendation label.

This table is a guide to the size of cylinder required, to provide a satisfactory hot water service to the average typical household, on the hours of electricity supply shown.

Cylinder Volume	Typical Application	Number of Bedrooms	Designed Occupancy No. of People	Electricity Hours of Supply
135 ltr 180 ltr 225 ltr	Small House Av. House Large House	3 Bedrooms 4 Bedrooms	2 Persons 3-4 Persons 5 Persons	Controlled off peak electricity supply 16 hrs per day
270 ltr 360 ltr 450 ltr	Small House Av. House Large House	3 Bedrooms 4 Bedrooms	2 Persons 3-4 Persons 5 Persons	Night rate electricity supply 11pm-7am

Sizing Table for Grade "A" or Grade "B" Cylinders

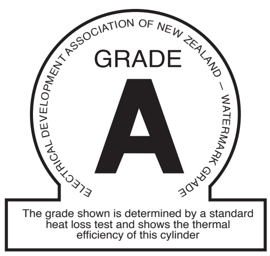


Figure 11.1: WaterMark system label

Manufacturers pay an annual licence fee to use the WaterMark as well as a levy of $1 to the EDA for each cylinder labelled. This is used to fund the operation and promotion of the scheme. To qualify for the label, test certificates from an approved independent laboratory must be provided by the manufacturer. There is an arrangement between the EDA and the Standards Association for checks on cylinders to ensure compliance.

Currently, the grades of low pressure hot water cylinder available on the New Zealand market fall into three levels: "A" grade having a heat loss that aligns with NZS4602:1988 and NZS4606:1989; "B" grade that aligns with the cylinders being manufactured using foam insulation that approximates to 25 mm in thickness and performs according to the appropriate test; and "C" grade which aligns with the heat loss from cylinders manufactured in the 1970s. A similar grading system is used for high pressure water cylinders. In this case, the relevant standard for "A" grade cylinders is NZS4606:1989.

While a "D" grade also exists, it seems manufacturers do not want this grade label on their cylinders. There is, however, no information on the label that expressly reveals that there is a hierarchy of efficiency from Grade A down to Grade D. The label does not contrast the energy losses of the various grades. It is assumed that by having an alphabetical grade on cylinders, purchasers will make themselves aware of the differences between grades. Not all cylinders are labelled. If a cylinder complies with the "A" grade requirements there is an incentive for the manufacturer to seek a label. Unless a cylinder carries the "A" grade WaterMark, it is a reasonable conclusion that it is a lower grade.

There is provision to extend the grading system in future to Grade AA and Grade AAA if manufacturers sufficiently improve the performance of the most efficient cylinders.

The label showing recommended cylinder volume provides advice on the selection of an appropriate cylinder size, based on duration of electricity supply (night rate vs. off-peak) and household size. There are two such recommendation labels, one for Grade A and Grade B cylinders and one for Grade C and Grade D cylinders.

Table 11.1 shows the standing heat losses from different cylinder grades according to the standard test. While the differences in practice may be reduced where there is a frequent and heavy hot water draw-off, they will still be significant and justify consumers purchasing "A" grade cylinders. Over the course of a year, a 270-litre "A" grade cylinder could save over 700 kW of electricity, or around $60 in power bills, compared with a "C" grade cylinder. Electricity savings will quickly repay the small extra investment in the better cylinder.

Cylinder Size (ltr)	**Grade A**	**Grade B**	**Grade C**	**Grade D**
135	1.4	1.8	2.8	3.2
180	1.6	2.0	3.2	3.6
225	1.8	2.3	3.6	4.0
270	2.0	2.56	4.0	4.6
360	2.5	3.2	5.0	5.8
450	2.9	3.7	5.8	6.7

Table 11.1: Heat loss from different electric hot water cylinder wraps

The next subsection indicates that in many cases, even the level of insulation on "A" grade cylinders is likely to be economically sub-optimal.

Retrofit Cylinder Wraps

The large number of inefficient electric hot water cylinders in service, possibly over 750,000, makes a retrofit solution very important. Cylinder wraps are a suitable retrofit in many cases, but they are under utilised.

Cylinder wraps consist of a 50 mm thick fibreglass blanket faced with a flame retardant foil on the outside. They are marketed in one size that fits all common sizes of electric hot water cylinder. The wrap can be trimmed to size if it is too large for the cylinder in question. Installation is usually left to the householder. In at least one part of the country, Christchurch, a commercial operation puts together its own cylinder wrap materials and provides a fitting service. This particular commercial operation is connected to a voluntary community group, Community Energy Action. The local power company, Southpower, refers enquiries for cylinder wraps to the community group.

The effectiveness of cylinder wraps has been examined as part of an EECA demonstration programme (EECA, 1991). At the time of the programme, the cost of wraps was $75, but they are now cheaper. The Christchurch operation installs them for around $60. The demonstration project examined three cylinders of different ages insulated with different materials and thicknesses. The benefit of the wrap varied with the location of the cylinder (underfloor versus in a water cupboard) and the thermostat temperature. The general conclusion was that a household with a 182-litre cylinder could expect to save about 600 kWh or approximately $50 per year (8c/kWh). At a cost of $60 for the wrap, this is a payback period of one year and an excellent return on investment (see Chapter 15 for the relationship between payback periods and return on investment).

Cylinders that only meet the WaterMark “B”, “C” or “D” grades should be wrapped. Figure 11.2 shows the standing losses under standard test conditions for a range of grades with and without the normal cylinder wrap. Wrapping an “A” grade cylinder could save around 0.75 kWh per day, 270 kWh per year, or around $20 to $27 per year, depending on power prices. This indicates a payback period of between two and three years, which corresponds to a good return on investment, especially for a long-lived item. If in doubt about the benefits of wrapping an “A” grade cylinder, the priority should be to wrap those with thermostats regularly set high or installed in cold or draughty places (e.g. basements).

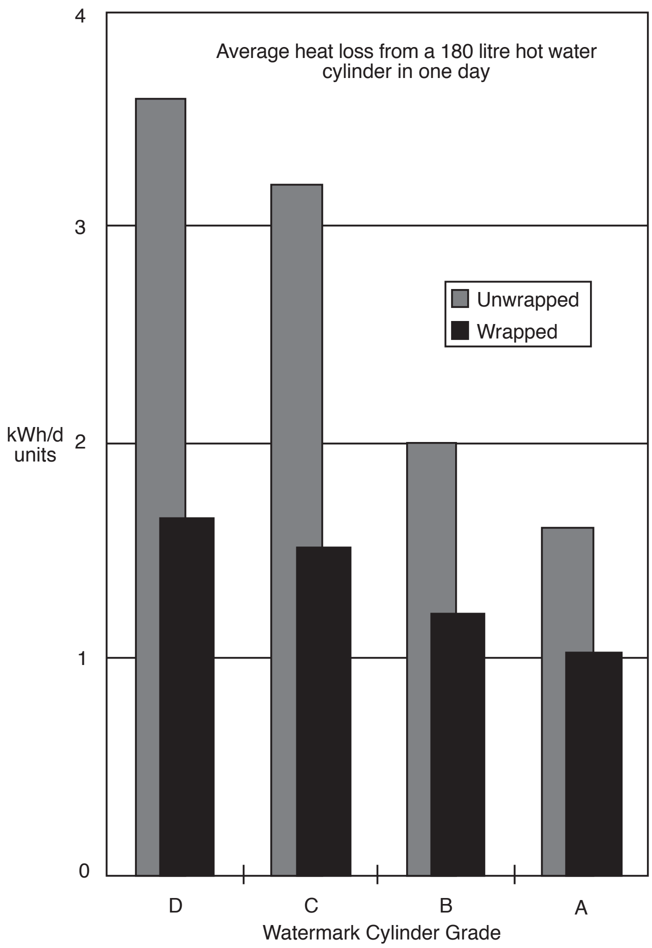


Figure 11.2: Effect of wrapping electric hot water cylinders

The main barriers to cylinder wraps appear to be the difficulty some people anticipate in fitting them — the actual problem of awkward access and lack of space with cupboard installed cylinders, or concern over the loss of airing effect in cupboard-installed cylinders. There are, however, many old hot water cylinders that these concerns do not apply to, and which should be wrapped. The loss of an airing cupboard warrants comment. The standing loss from a C-grade cylinder, for example, could be reduced by around 600 kWh per year, if it is wrapped. The wrapped cylinder will still lose heat and provide an airing effect, albeit reduced. The installation and use of a 20 to 30 W cupboard heater in a suitable part of a home for eight to nine months of the year will provide an alternative clothes airing facility and will only need 120 to 200 kWh of electricity. Wrapping the cylinder, reducing its airing load and making up the difference with a small cupboard heater is a more energy efficient approach.

11.4 Electric Heat Pumps -— Quantum Unit

Heat pump technology has already been outlined in Chapter 8 “Electric Space Heating”, Section 8.3. This section describes an efficient water heater that uses a heat pump that can have its performance enhanced by solar gain.

The Quantum hot water unit was developed by Melbourne University and refined by Tasman Energy in New Zealand. The Quantum unit is an air-to-water heat pump that has the potential to reduce electricity consumption by around 60% to 70% compared with electric storage and instantaneous heating systems.

The unit consists of a low pressure water storage cylinder and a heat pump system. The standard compressor for the heat pump is a high efficiency 650 Watt rotary unit, but there are a variety of cylinder sizes and the option of a 1500 Watt unit is available for the largest, 360 litre, cylinder. The evaporator panels have been specifically designed for air-source heat pumps. They can be configured with the water cylinder either as a split or compact system. In the compact configuration, the evaporator panels are wrapped around and mounted on the cylinder. This system is used when the whole Quantum unit is located outdoors.

In the split system, the evaporator panels can be located on a roof, in a ceiling space or in any convenient outdoor location. The main constraint is a maximum separation of the cylinder and evaporator panels of 10 metres. It is roof mounting of the evaporator panels that opens up the possibility of solar boosting.

The condenser, which transfers heat to the water, is a helical copper coil bonded to the outside of the water cylinder. The refrigerant used in R22 (chlorodifluoromethane, $CHClF_2$), which is a HCFC. Icing of the evaporator (e.g. during frosts or snow falls) does not severely affect its performance. The unit can operate efficiently at temperatures down to -20˚C. Figure 11.3 shows the basic layout of the evaporator panel, the water cylinder and condenser.

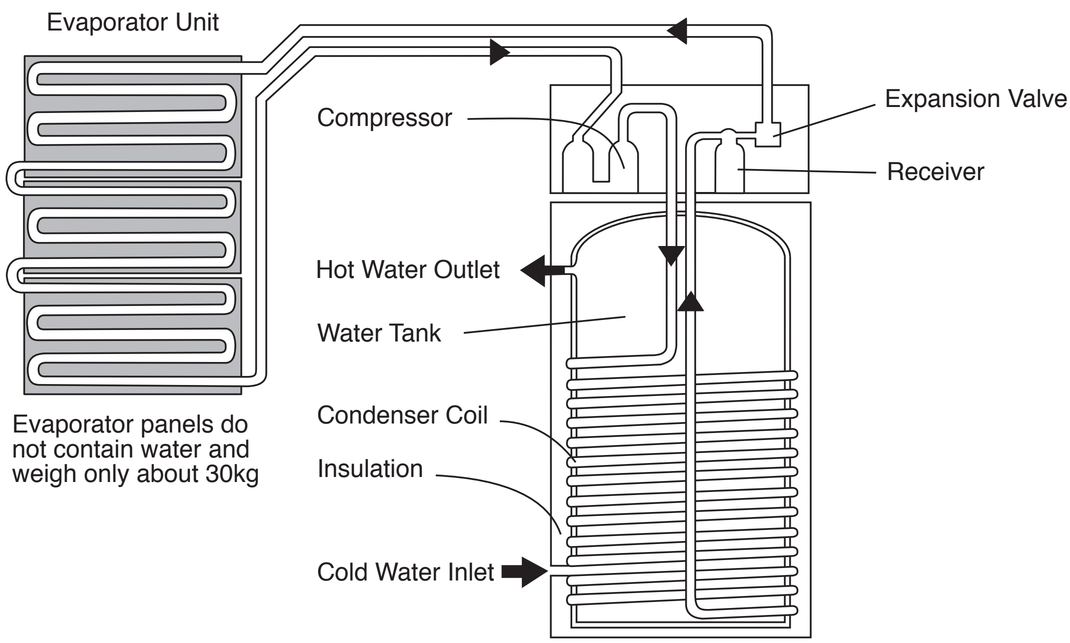


Figure 11.3: Schematic of the Quantum hot water unit

Performance

Figure 11.4 shows the roof installation of Quantum condensers at the Seifried Vineyard restaurant. The Cawthron Institute has examined the efficiency of Quantum units installed in Nelson and the DSIR has subjected them to heat loss tests. The DSIR tests show that the units have standing losses that are lower (that is, perform better) than the Grade A Performance rating of NZS4602:1988 (Low Pressure Copper Thermal Storage Electric Water Heaters). Cylinder temperature profile measurements show a very even temperature, and consequently a greater thermal storage per volume, than that achieved with standard electric storage cylinders.

Figure 11.4: Quantum collectors at Seifried Vineyard restaurant

Results from the Cawthron Institute (see EECA, 1993) indicate that the performance of the heat pump varies with the ambient temperature and, when the evaporator is exposed to the sun, the amount of bright sunlight. The COP (Coefficient of Performance) almost doubles when the sun is shining. In sunless conditions the COP for average Nelson conditions will be in the range of 2 to 3. In sunny conditions, the COP will be in the range of 3 to 6. Figure 11.5 shows the COP variation for different ambient temperatures and sunlight levels. As a comparison, the COP for a standard electric hot water unit would be in the range of 0.75 to 0.9.

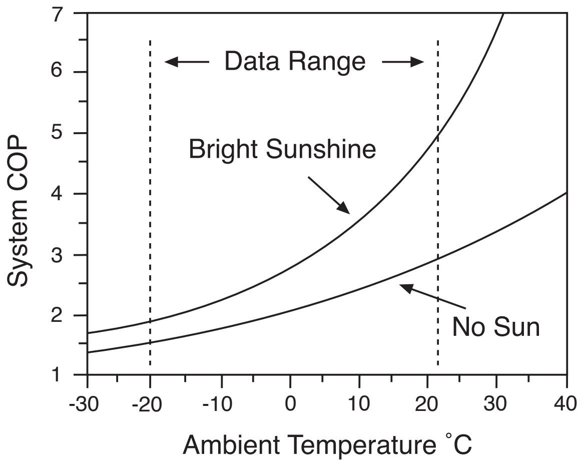


Figure 11.5: Predicted performance of Quantum collectors

The average overall COP based on Nelson weather is expected to be around 2.9. It is difficult to be precise about the annual solar contribution to the Quantum unit's performance, but it could mean a reduction in the power consumption by 20% or more, compared with a compact unit that relies solely on ambient temperature.

While roof location of the evaporators improves an already efficient system, the major efficiency gain with the Quantum unit comes from its use of basic heat pump technology

11.5 New Wood Burner “Wetback” Systems

Conventional wetback systems suffer a number of limitations. They rely on a thermosyphon effect to circulate water from the storage cylinder through the solid fuel heater and back to the cylinder. Consequently, the hot water cylinder has to be raised above the woodburner and located less than three metres away. This often means that the cylinder is not close to hot water loads, thus increasing water distribution energy losses. The thermosyphon pipe needs to be of large diameter (25 mm) to reduce flow resistance.

Wetback systems need to be installed by experienced tradespeople to ensure satisfactory performance. Even then, consumers are often dissatisfied with the result. Most systems that do perform reasonably well still need boosting with an electric element.

New wetback technologies have been developed by High Temp Industries in Masterton. Put together to form the Pulse Flow system, these technologies overcome the limitations of the conventional thermosyphon system. The Pulse Flow system uses a special expansion effect valve to drive water around the heating loop. It does not rely on a thermosyphon effect or an electric pump. Consequently, the water cylinder can be on the same level as the heater (or above or below) and located up to 20 metres away. The water heating circuit can use a 20 mm pipe since flow resistance is a minor issue. The Pulse Flow system is suitable for integration with low pressure (pressure up to eight metres), open vented hot water systems, using either header tanks or pressure-reducing valves. The system can run off the solid fuel heater alone, that is without electric boosting, provided good fire management is practised. However, the building code requirement that potable hot water supplies must always exceed 60˚C, may necessitate an electric element and thermostat.

The key element of the Pulse Flow system is the Hi-Temp water heater. This award-winning design comes in two models, a curved or planar grid of six flattened copper riser tubes between two manifold pipes. Figure 11.6 illustrates the two heater models. One of these two types of grids is fitted in the top or rear of the solid fuel heater, depending on appliance type. It takes up little firebox space. Flames from the fire pass heat through a relatively large surface area to a small volume of water in the Hi-Temp heater grid. The flattened riser tubes enable fast and efficient heat exchange.

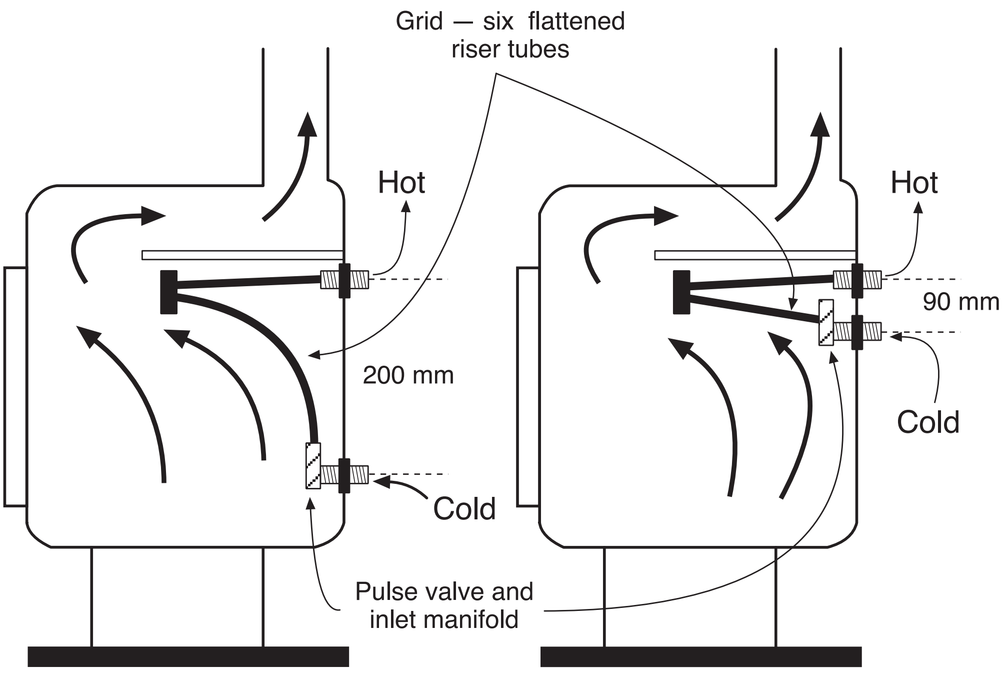


Figure 11.6: Pulse flow system Hi-Temp water heater

The output of the Hi-Temp heater is rated at 3.6 kW. With a pressure head of 2.5 metres, the heater will heat a 110-litre water cylinder from ambient to 50˚C in about three hours. As a rule, cylinders smaller than 110 litres should not be used as standing losses are too great (surface area to volume problem). Extra insulation may, however, overcome excessive losses from a cylinder of marginal size.

The Hi-Temp heater and its circuitry has been appraised by BRANZ and certified as meeting the relevant New Zealand Building Code requirements for durability (NZBC B2.3(d)), piped services performance (NZBC G10.3(a)) and water supply (NZBC G12.3.4). The appraisal certificate (BRANZ, 1994) sets out a number of qualifications and clarifications. For example, the BRANZ opinion on durability is based on continuous or regular operation using non-treated wood rather than coal as the heater fuel.

Part of the NZBC water supply requirements are met by placing a tempering valve on the hot water outlet. Figure 11.7 shows the two circuitry options for header tank and flow reducing valve situations. Slightly different circuitry is used where there is a concrete floor that does not allow underfloor placement of the cold water line. The pulse valve prevents true back circulation. When the heater is not in operation, a degree of in-pipe circulation and minor heat loss could occur in the hot flow line. BRANZ notes that with a header tank setup, this in-pipe circulation will be prevented providing the hot flow line enters the vent 50 mm above the header tank water level.

One of the amenity features of the Hi-Temp heater circuitry is the absence of banging and crashing noises caused by normal wetback systems. The absence of steam or airlocks makes for quiet operation.

The Hi-Temp heater and Pulse Flow system are energy efficient technologies on several counts. They provide more efficient water heating than conventional wetback systems. Many of these systems rob the heater of space heating performance without giving a commensurate amount of water heating. This new technology has a low impact on space heat output and efficiently heats water. The system is not prone to subsequent heat loss through back flow and it allows convenient cylinder placement close to hot water demand.

By overcoming the limitations of conventional wetbacks, the Hi-Temp heaters could make woodburners more popular as a hot water source. On a total energy basis, combined space heating and water heating using woodburners fitted with the Hi-Temp heater is likely to be more efficient than burning fossil fuels to produce electricity for conventional hot water cylinders. This provides an energy and environmental advantage. The environmental benefit is amplified as wood is a renewable, greenhouse-friendly fuel.

11.6 Natural Gas — Rinnai Infinity

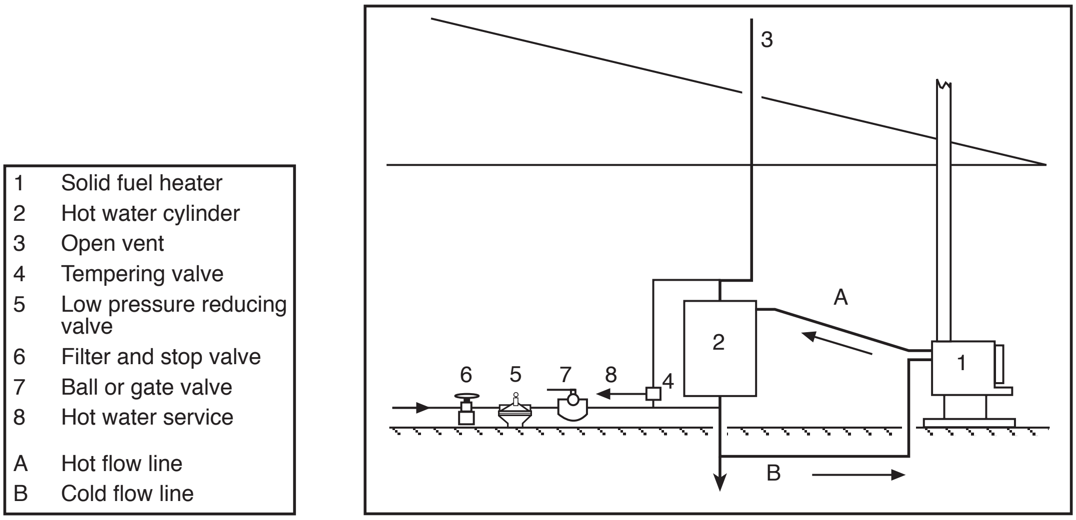
This section describes some of the features of the Rinnai Infinity, an efficient instantaneous gas water heater. This heater is quite sophisticated and its full operation cannot be covered here. Additional information is available from Rinnai New Zealand Ltd. The results of some energy efficiency tests on the Rinnai appliance and electric storage heaters are presented here.

Instantaneous heaters have the potential to efficiently supply hot water, but in the past they have had shortcomings. The advantage of having no water storage and associated standing losses has been eroded by certain system inefficiencies or problems with supplying the level of service expected by householders:

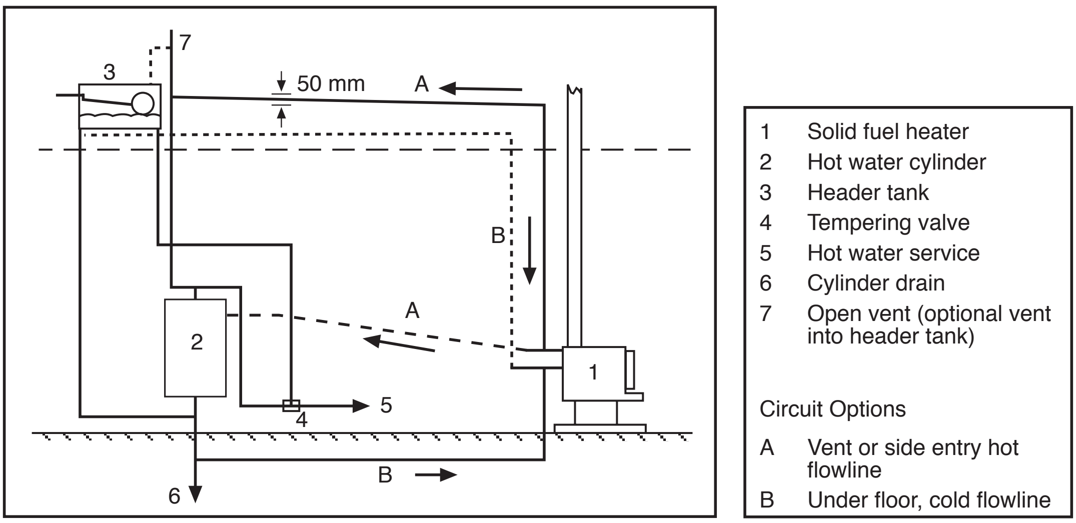
- hot water flow rates and temperatures fluctuated too much, resulting in consumer dissatisfaction and wasted water;
- wasteful pilot flames were used and combustion control and heat exchange efficiency were second-rate, resulting in excessive heat loss in flue gases; and
- no provision was made for remote temperature adjustment, so excessively hot water was often distributed with attendant energy losses and safety risks.

The Rinnai Infinity series of water heaters have combustion and heat exchange systems and water management systems that have sufficient electronic monitoring and response to overcome these shortcomings. Electronic control of the Infinity series heaters is achieved by using a printed circuit board (PCB) for routine translation of monitoring data and a central processing unit (CPU) on the PCB to manage variables.

In the discussion that follows, the shorthand EMC unit (electronic monitoring and control) will be used for electronic hardware and software that drives the heater systems.



(a) Typical Hi-Temp low-pressure reducing valve open vented circuitry



(b) Typical Hi-Temp low-pressure open vented circuitry

Figure 11.7: Low pressure circuitry — under floor situation

The main monitoring and control features of the combustion and water systems are described below with reference to the Rinnai Infinity 24, the model with the highest maximum flow rate. The Infinity 24 can supply water at flow rates varying from 2.7 to 24 litres per minute on the basis of 15˚C input temperature and an elevation of 25˚C. This model is suitable for larger homes with two bathrooms or ensuites. The maximum hot water temperature at the appliance outlet can be preset at the EMC for 40˚C, 50˚C, 55˚C and 75˚C in order to satisfy safety regulations. Within the constraint of the preset maximum, it can also be varied in 16 steps from 37˚C to 75˚C at remote control units. These units are usually located in kitchens, bathrooms and ensuites, which means that when the shower is in use, a lower water temperature can be delivered (42˚C) than that required in the kitchen (50˚C). The water heater is designed for installation on the outside of an external wall, thereby saving floor space.

Water Management System

Figure 11.8 shows a schematic of the Infinity 24 water management system. The key features are the feedback (FB) and feedforward (FF) functions:

- FF1: incoming water temperature;
- FF2: water flow; and
- FF3: temperature selected at the remote control.
- FB1: temperature outgoing water; and
- FB2: heat exchanger water temperature.

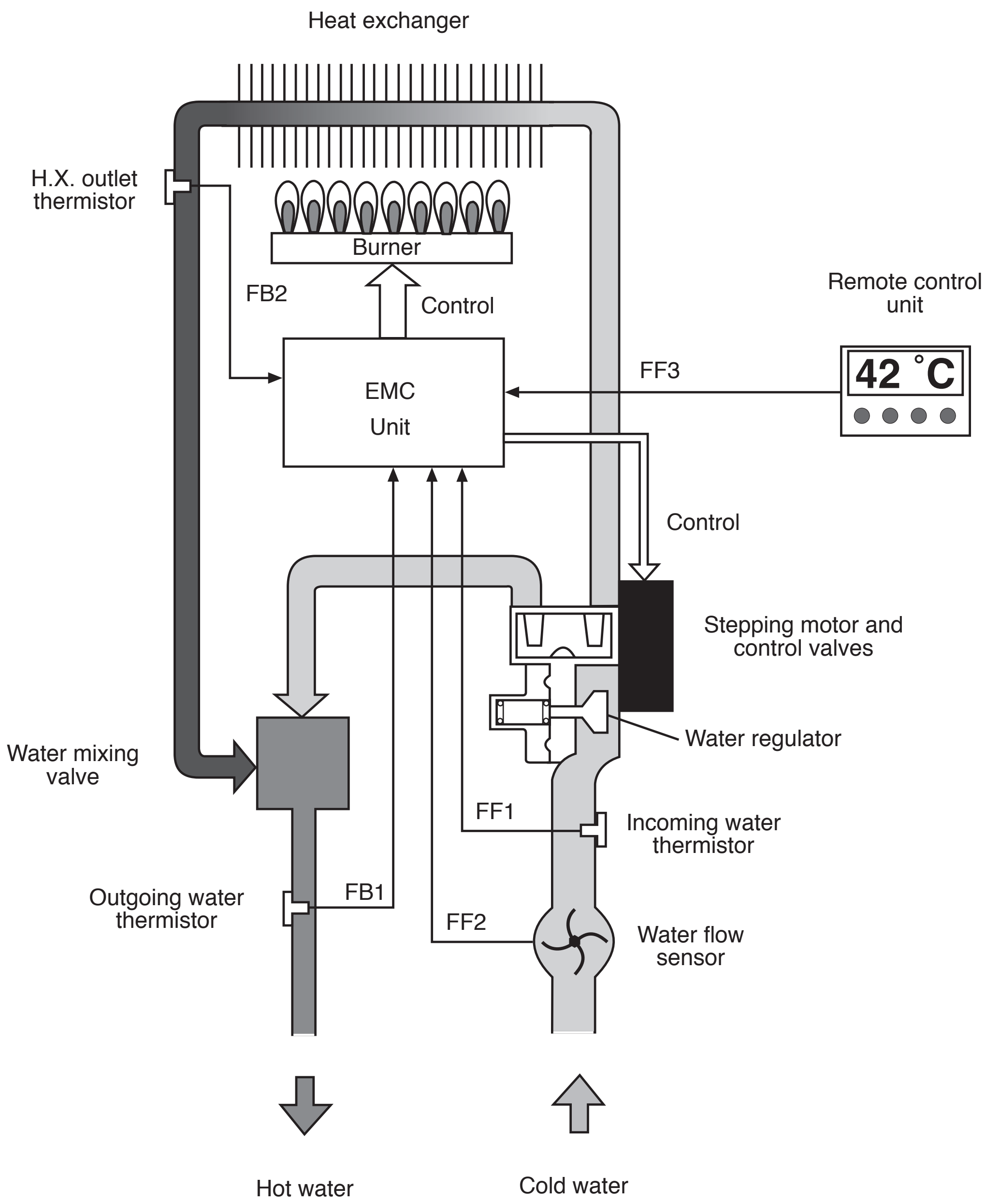


Figure 11.8: Schematic of Rinnai Infinity water management system

When a hot tap in the home is turned on, water begins to flow through the appliance. The revolution speed of a turbine in the water flow sensor is used by the EMC unit to calculate flow rate. When the flow rate exceeds the appliance minimum, the ignition sequence begins (unless there is a cold water "sandwich" potential, which is discussed below). The normal objective of the combustion heat-exchange system is to produce a controlled amount of water heated to 60˚C. This temperature will prevent condensation inside the heat exchanger. Incoming water temperature is monitored and the EMC unit calculates the amount of water heated to 60˚C that needs to be mixed with the ambient cold water to produce the temperature set at the remote control.

A key piece of hardware is a series of motorized (servo) valves that control the amount of water that goes through the heat exchanger and the amount of cold water that is bypassed and subsequently mixed with the hot water to obtain the right temperature and flow rate combination. An electric stepping motor drives these valves on instructions from the EMC unit. A mechanic water regulator is provided upstream of these valves to ensure they provide the correct flow output across a range of water supply pressures. The regulator has its limits; while the Infinity 24 will operate at very low water pressures, maximum performance is not reached unless the incoming pressure is 200 kPa or more.

After mixing the outgoing hot water, temperature is monitored to provide feedback. The EMC unit checks the temperature selected on the remote control against the temperature indicated by the outgoing water thermistor, and makes adjustments to the gas flow rate or water flow rate through the heat exchanger, as required, to maintain the target temperature.

Feedforward and feedback is rapid and precise (0.01 second data sampling, 10-bit resolution, and 0.1˚C precision). Fluctuations in water temperature at the bath, handbasin or shower are imperceptible, even when other hot taps are turned on or off.

The first time a hot tap is turned on in the morning, there will be a pulse of cold water from the supply line and this passes through the heater before the combustion takes effect. The water then quickly goes from cold to warm to the target temperature. A particular challenge for instantaneous heaters is the so-called cold water sandwich effect that can occur when a tap is turned off and then turned back on shortly afterwards.

When combustion in the water heater stops because a hot tap is turned off, the hot water remaining in the heat exchanger absorbs the residual heat of the heat exchanger and becomes hotter. In conventional systems, the next time the tap is turned on, this hot water flows out first. Due to the time lag between the new flow of water, burner ignition and energy input to the heat exchanger, first hot then cold water flows before stabilizing. This is known as the cold water sandwich. It is inconvenient as it causes wasted hot water. The Infinity 24 avoids this problem.

With the Infinity 24, once a hot tap has been turned off and combustion stops, the outgoing water thermistor and heat exchange outlet thermistor monitor the hot water temperature for eight minutes as it changes continuously due to residual heat in the heat exchanger. The EMC unit prepositions the water control valves (heat exchanger water flow and the bypass water flow) so that they are in the correct position to supply hot water at the preset temperature, before the gas ignites. The quick ignition once combustion is needed, the efficient heat exchanger and the water management system means that a slug of cold water does not flow down the hot water supply line. Perfect achievement of the target temperature shortly after turning off a hot tap is not possible, but the maximum temperature range for the Infinity 24 of +/- 3˚C for a short flow period after it has been stopped and restarted within five minutes is an excellent result.

Combustion and Heat Exchange Systems

The Rinnai Infinity water heater does not have condensing heat recovery, but is nonetheless an efficient appliance. In principle, an instantaneous water heater could have a secondary heat exchanger to preheat the incoming water, but it is difficult to design in the extra hardware at a low enough cost. The Infinity has a range of other combustion features that ensure that the appliance is energy efficient:

- combustion modulation/high efficiency across heat outputs;
- excellent control of the air-to-gas ratio;
- near constant temperature lift;
- efficient heat exchange unit; and

- electronic ignition rather than a pilot flame.

The combustion chamber is made of aluminised steel and the burner assembly is made up of 18 stainless steel bunsen burners. A two chamber aluminium manifold with 18 injectors supplies gas to the burners. A combustion fan supplies air for combustion. Modulation is achieved via a modulating valve and a changeover valve that controls whether one or two manifolds are supplying gas. This combination provides the flexibility needed for efficient operation.

If a person turns on a hot tap sufficient to create the minimum flow through the Infinity 24, the combustion-ignition sequence begins. The combustion fan prepurges the combustion chamber. The burner is ignited by direct electronic ignition and the flame is sensed with a flame rod.

From the information provided by the water flow sensor and the incoming water thermistor, the EMC unit determines how much gas is needed to heat the water to the temperature selected at the remote control. The EMC unit sets the combustion fan speed to the appropriate level by varying the DC voltage to the fan motor. The opening degree of the modulation valve and the position of the changeover valve depend on the combustion fan speed. Together, these settings ensure the correct air/gas ratio for combustion.

The EMC unit continually makes adjustments in order to maintain a constant water temperature output from the heat exchanger, adjusting the combustion and gas input, the water flow rate through the heat exchanger and cold water mixing as necessary. Achieving water temperature targets by mixing cold water with water heated to the set level goes some way towards allowing an optimal heat exchange design. When the water tap is turned off, the water flow sensor signals the EMC unit, which then switches off the combustion fan and closes the gas valves. As mentioned above, subsequent ignition may be delayed to avoid creating a cold water sandwich effect.

Energy Efficiency Tests

The Gas Association of New Zealand Inc. (GANZ) has commissioned comparative tests of the Rinnai Infinity 20 (a smaller model than the Infinity 24 and suitable for a typical single bathroom home) and several commonly purchased electric storage heaters (GANZ, 1993). Typical operating cycles for a two, four, and six person family were established and the energy efficiency for each heater during the three duty cycles was measured. Full tests results are available from GANZ and a summary of the main points is presented here.

Firstly, the Infinity 20 was able to supply hot water at a constant end-use efficiency of 77% for all three family sizes, a very creditable performance for a non-condensing appliance. Electric storage heaters show improved efficiencies for heavier duty cycles. This is because storage losses are a lesser proportion of the total energy input as the throughput increases. Figure 11.9 shows the end-use efficiency results. At the low duty end, the Infinity is more efficient than the older Rheem model and comparable with the new model. The Infinity 20 can supply hot water at the required temperature on demand. In practice, electric storage heaters often cannot do this, so they impose a degree of enforced energy conservation.

End-use efficiency is only one aspect of energy use. When the full fuel cycle is considered, the Infinity 20 outperforms the electric storage heaters. Figure 11.10 shows the results, assuming electricity comes from a generation mix with 80% hydro and the balance geothermal and fossil fuel thermal power. The Infinity's efficiency falls to 74% to allow for energy consumed in gas transmission and distribution. Thermal power generation and transmission/distribution losses have a greater effect on the electric appliances. There is an argument that the basis of comparison should be marginal electricity generation, which is almost all fossil-fuel based thermal. In that case, the efficiency of electric water heating falls to 20% to 30% depending on appliance make and model. This difference, however, is not reflected in the prices that consumers pay for gas and electricity.

A side feature of the tests was that only one of the electric heaters met the heat loss standard (non-compulsory) in NZS4602:1988 for low pressure cylinders and NZS 4606:1989 for mains pressure cylinders. A worrying factor is that one of the cylinders appeared to not meet the standard even though it had a WaterMark "A" grade label on it.

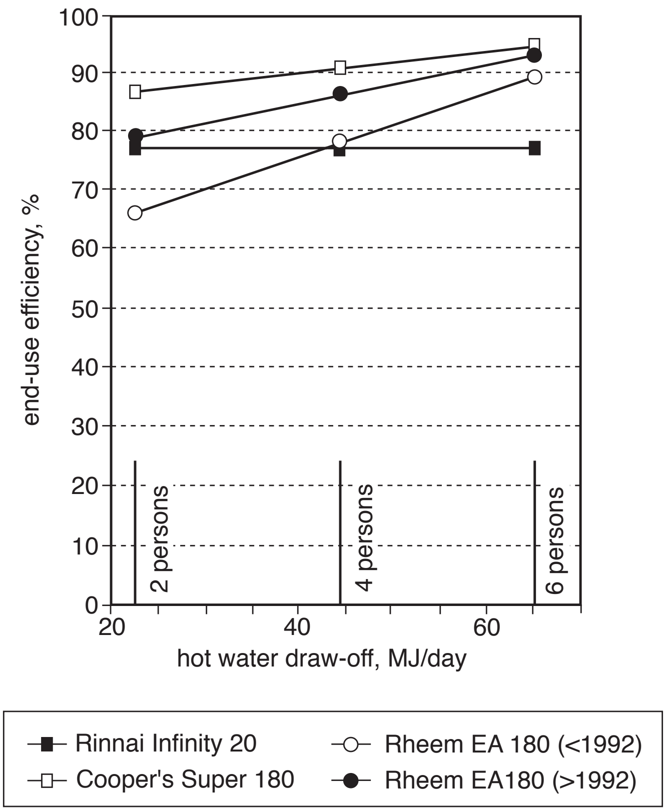


Figure 11.9: End-use efficiencies of water heaters

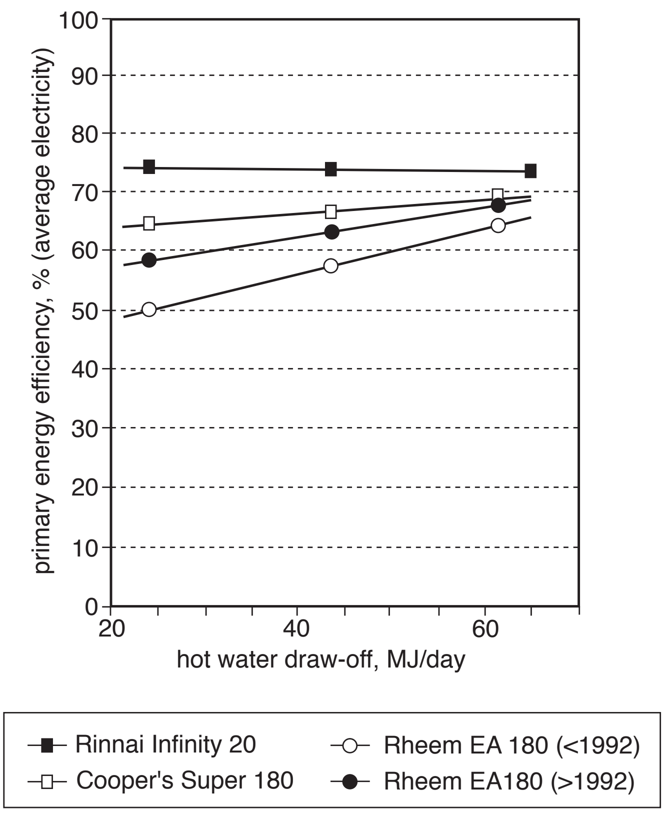


Figure 11.10: Primary energy efficiency, based on average losses for the electricity system

References

BRANZ (1994). “Hi-Temp Water Heater” *Appraisal Certificate No. 281 (1994)*, Building Research Association of New Zealand.

EECA (1991). *Reduce Electric Hot Water Heating Costs with a Cylinder Wrap*, Project Summary 25, Energy Efficiency and Conservation Authority, Wellington.

EECA (1993). *A Quantum Leap into Hot Water*, Demonstration Project Profile, Energy Efficiency and Conservation Authority, Wellington.

EECA (1995). *Making the Most of your Hot Water System*, Energy Efficiency and Conservation Authority, Wellington, 1995.

GANZ, (1993). *Performance and Operating Costs of Electric and Natural Gas Water Heaters*, Gas Association of New Zealand (Inc), Wellington.

Henderson (1994). *Economic and Financial Potential for Energy Efficiency in the New Zealand Residential Sector*, Report to the Energy Efficiency and Conservation Authority, Wellington.

NZBC Clause B2.3(d) (1992). “Durability”, *The New Zealand Building Code Approved Documents 1992*, Building Industry Authority, Wellington.

NZBC Clause G10.3(a) (1992). “Piped Services Performance”, *The New Zealand Building Code Approved Documents 1992*, Building Industry Authority, Wellington.

NZBC Clause G12.3.4 (1992). “Water Supply”, *The New Zealand Building Code Approved Documents 1992*, Building Industry Authority, Wellington.

NZS4602:1988. *Low Pressure Copper Thermal Storage Electric Water Heaters*, Standards New Zealand, Wellington.

NZS4606:1989. *Storage Water Heaters*, Part 1 (1989) General Requirements; Part 2 (1989) Specific requirements for water heaters with single shells; Part 3 (1992) Specific requirements for water heaters with composite shells. Standards New Zealand, Wellington.

Chapter 12
Solar Water Heating

12.1 Introduction

The maximum energy intensity of sunlight is about 1000 W/m^2 and the number of sunshine hours in a year ranges from about 1600 in Invercargill to about 2450 in Blenheim, with around 2000 hrs/yr in the main centres of population. The energy falling on a horizontal surface ranges from about 7 kWh/m^2/day in summer to about 1.4 kWh/m^2/day in winter. The amount of sunshine falling on the roof of a typical New Zealand house in a year is almost 150,000 kWh or over 10 times the total electricity needs of an average household. Providing it can be converted to a useful form, solar energy could meet all residential energy needs. The main challenge is how to collect the energy given that both the source and energy uses are intermittent and follow different patterns.

Solar energy needs to be converted and then stored for use when the resource is unavailable or inadequate. The main applications of solar energy are high temperature heat using sunlight concentrating devices, photovoltaic conversion and passive solar space heating and water heating. Photovoltaic conversion provides the most flexible energy form, namely electricity, which can be used for heating, appliances, etc. The efficiency of energy conversion is, however, presently fairly low (less than 20%) and photovoltaic equipment is relatively expensive. This chapter focuses on solar water heaters that use the sunlight in a relatively simple and direct way rather than on photovoltaics or high temperature heat devices.

Direct solar water heating is a technically simple process, although innovative designs have been developed to improve the conversion efficiency and/or to reduce costs. Solar water heating is considered environmentally benign. It uses a renewable energy source, thereby conserving fossil fuel energy resources and avoiding greenhouse gas emissions. At face value, solar water heating systems do not appear to require more material inputs, that is metals, plastics, etc., in their construction than alternative heating systems. Solar systems use readily available rather than exotic materials.

The main perceived disadvantages of solar water heating are that it is dependent on an intermittent source of energy and, like many other demand-side management measures, it requires a significant capital outlay. This investment is recouped in the form of electricity or gas cost savings. Household consumers may be put off by the up-front costs and businesses may find the payback periods lengthy.

This chapter starts by describing the potential contribution of solar water heating to national energy efficiency; the amount of electricity generation that could be displaced in a typical household and across the nation if greater use was made of solar water heating. Section 12.2 ends with a brief discussion on the barriers to solar water heating. Section 12.3 looks at a number of general issues relating to the design of solar water systems. Finally, five different solar systems are presented in order to illustrate the various ways that these design issues are being addressed.

12.2 Energy, Economic and Environmental Implications

Household Water Heating

The amount of energy used for water heating in a typical New Zealand household is usually quoted at between 3000 and 7000 kWh per year with an average of about 3500 to 4500 kWh/yr. These figures are based on dated surveys and it is possible that, with the increasing use of washing machines for both clothes and dishes and the rising expectations of hot water availability (as evidenced by the use of larger hot water cylinders), the national average has increased.

The pattern of water use in a home and the availability of sunshine do not coincide, and consequently it is necessary to average the two out using a storage tank. The amount and temperature of water that can be stored from a solar system will depend mainly on the size of the storage tank, the area of the collector and the pattern of water use. The water use pattern is generally more regular than the solar availability pattern (that is water is used every day but the sun sometimes does not shine for several days at a time). In practical terms, this means that an alternative energy supply is needed to backup or boost the solar input.

It is normal practice to design the collector system to provide some fraction of the total annual energy requirement rather than the actual daily requirement. The percentage decided on is dependent on the storage one wishes to provide and the area of collector one wishes to install. In New Zealand, the rule of thumb guide to a cost effective system is to aim for about 50% to 75% of the annual energy requirement. On this basis, most New Zealand homes could save between 2000 kWh and 3000 kWh of electricity per year.

Nationwide Energy Implications

The national annual energy consumption for hot water production is thought to be about 5,500 GWh for electric cylinders and 385 GWh for natural gas systems. The hot water electricity demand represents about 20% of ECNZ's annual production. Any major increase in the use of solar water heating would have a significant effect on power demand by the domestic sector. The domestic market for water heaters is quite large. There are approximately 1.3 million dwellings in New Zealand and each year about 50,000 water systems are replaced or upgraded. Furthermore, around 20,000 new homes are built each year, each requiring a water heating system.

If over time solar water heating systems achieved a 50% penetration into the market, then approximately 1,650 GWh of power demand would be displaced (650,000 homes times 2500 kWh), or just over 5% of ECNZ's present output. While market penetration by solar water heaters has been poor to date, most of the reasons for this can be addressed or are no longer relevant (this point is elaborated shortly). Consequently, the gradual increase in sales of solar systems to around 30,000 units per annum over five to ten years is credible.

Economic Aspects

The cost of solar water heating is determined mainly by the capital cost of the units as operating costs are quite low. The benefit of solar heating is often expressed in terms of electricity consumption avoided; the average home could save around $300 per year on its electricity bill by investing in solar water heating.

Presently, the lifecycle costs on an electricity equivalent basis vary from slightly less than 10 c/kWh to around 15 c/kWh or more. If low temperature water is satisfactory (e.g. a heated swimming pool), then the costs will be lower than for a supplying hot water to showers, basins, etc. Either way, there are circumstances where solar water heating is already economic compared with alternatives. Solar heating is competitive with the lifecycle cost of hot water from a standard electric system of the same size, namely around 14 c/kWh. Night rate electric water heating is cheaper, but the outlook is for electricity prices to rise while the cost of solar technology is likely to fall — especially if sales increase to allow manufacturing economies of scale to be realised.

By displacing electricity use, solar water heating helps to delay investment in new power generation facilities. A significant feature of solar heating is that the energy is already delivered to the site. Where transmission or distribution systems are close to capacity, solar water heating could avoid the need for costly line upgrades.

The current installation rate of domestic solar water heaters is probably less than 300 per year. An industry producing 30,000 installations per year would provide employment for an estimated 400 to 800 people in production, sales and installation. It would support up to four to eight large manufacturing operations and over 100 individual installers. It would probably take at least two to three years to bring the industry up to this rate of production.

Environmental Issues

Solar with gas backup is the most environmentally friendly of the cost effective and practical water heating options available, as shown in Table 12.1. The primary input column in the table represents the amount of fossil fuel that is consumed to deliver the end use energy, based on either a combined cycle power station and

10% transmission losses or natural gas reticulation with 2.5% system energy needs. The system COP measures the ratio of energy output to energy input for the water heating appliance. An electric heat pump is the most efficient appliance. Teaming a heat pump up with solar heating would be an environmentally friendly system, but it creates practical difficulties (slow boosting rate) and would be very expensive.

Heater Type	System COP	Enduse kWh	Primary kWh
Electric Storage	0.85	5,700	13,900
Electric Instantaneous	0.95	5,100	12,500
Gas Storage Condensing	0.80	6,100	6,250
Electric Heat Pump	2.5	1,900	4,650
Solar — Electric	2.5	1,900	4,650
Solar — Natural Gas	2.0	2,400	2,450

Table 12.1: Indicative domestic hot water system performance and annual energy use for a family of six

Solar heating with electric resistance backup is comparable to heat pump technologies in terms of primary energy input. Presently the dominant form of water heating is all-electric resistance heating. Converting a home to solar-electric system would mean around 9000 kWh per annum of primary energy savings (natural gas or coal). This savings translates into a carbon dioxide emissions reduction of around one tonne per household.

If, as suggested above, around one half of New Zealand homes gradually converted to solar water heating, then carbon dioxide emissions could be 650,000 tonnes per annum lower than otherwise. This represents about 10% of current emissions. In 10 to 20 years solar water heating could be making a major contribution to New Zealand meeting obligations under the Framework Convention on Climate Change or subsequent international treaties.

Barriers to Solar Water Heating

While it has a bright future ,the solar water industry in New Zealand is currently small. The reasons for this situation are largely historic, but the industry will need to overcome its legacy if it is to grow rapidly.

For many years, solar water heating has been seen as an area for amateurs. Because it has been possible for individuals to construct quite workable systems from surplus materials and secondhand components, the industry has acquired a "non-professional" image. In the 1970s, there was some justification for this image. During that period, there was a proliferation of solar water heater designs, a number of which were marketed by one-man backyard businesses, and some of which were ill designed and badly made. Most of the 30 or so companies that were marketing in New Zealand in the late 1970s have now disappeared and there remain a few that have concentrated on systems that have a good balance of cost and performance and are well constructed. Nonetheless, the public in general and some professional engineers and architects often still see solar water heating as a low technology, low quality or otherwise second-rate heating option.

During the 1980s, up-front cost presented a serious barrier and the idea that solar water heating is for enthusiasts that are willing to pay the price still persists. Until recently, domestic electricity costs were artificially low and interest rates were high. Solar water heaters were relatively expensive and the simple payback time for a solar water heater was in the range 15 to 20 years. There was little attraction in buying a solar water heating system on which the return in electricity costs avoided was about 8% to 10% when the bank gave 20% on a call account. Now, however, the return on a solar water heater is usually in the range 8% to 12% (equivalent tax paid), whereas the return on a bank call account is around 5% to 6% (before tax).

From the point of view of the domestic investor, the value of solar water heating has improved significantly over the past ten years. Even from a national point of view the value of solar water heating has changed. Marginal costs of electricity production are projected to rise significantly and some areas face supply constraints as load grows. True marginal pricing for electricity generation and supply and financial recognition of their environmental externalities would further improve the economics of solar water heating. A carbon tax on fossil fuel use to cover the greenhouse effects of new thermal power generation would place solar water heating on a more even footing with grid electricity.

The solar water industry itself has a role to play in promoting a new image. The reality, though, is that with low sales volumes, there is little surplus money for promotions, lobbying, education etc. As a result of the electricity sector reforms, power companies are now taking an interest in solar water heating. This interest may be based on widening the services available to their customers, enhancing their image by being associated with a green product, through to the potential for solar heating to avoid line upgrades or replacements. A case can be made for the EECA to use some of its resources to promote solar water heating to different audiences.

It would also be very helpful if engineers and architects who can influence decisions on water heating systems were to review their perceptions of solar technology. It is hoped that the discussion that follows will show that solar water heating technology is both simple and yet sophisticated. Advances in design, materials and manufacture mean that a reliable, cost-effective alternative to all-electric or natural gas heating is available.

12.3 Solar Design Considerations

The performance and economics of solar water heating depends to a degree on environmental conditions, such as the amount of available sunlight and whether the site is frost-prone. The quality of the water supply, whether it is hard, corrosive, saline or dirty, is a factor that also has to be taken into account. Systems are usually designed to cope with reasonable worse case environmental conditions. Most of the differences in solar design are due to different approaches in dealing with the trade-offs between:

- efficiency of heat transfer;
- amount and cost of materials;
- fabrication and installation costs;
- control and integration systems; and
- architecture and aesthetic considerations.

Solar water heaters almost invariably operate by absorbing solar energy on a blackened surface and then conducting the derived heat to a water flow and, hence, to a storage cylinder. The cylinder provides the buffer between solar availability and water demand. Water circulation between the absorbing element and the storage cylinder can be passive via a thermosyphon or active using a pump. The absorber is usually in the form of a flat plate with attached water tubes running between a supply and a delivery header. The absorber unit is usually placed in a weatherproof case with insulation behind the absorber and a transparent cover in front.

Collector — Efficiency Principles

The efficiency of a flat-plate tube-on-sheet collector depends on the intensity of the solar radiation, the operating temperature of the panel, the general construction of the panel, the transmission of the cover, the absorptivity of the sheet and the quality of the insulation. There are various compromises made in these factors, but in general the overall performances of commercially available flat plate collectors are fairly similar and can be described by the Hottel-Whillier-Bliss (HWB) relation shown in Figure 12.1. Efficiency falls as attempts are made to raise the panel output water temperature (T_{panel}) or if the ambient air temperature ($T_{ambient}$) is low or there is less sunshine (I falls).

Figure 12.1 shows that the maximum efficiency of conversion is around 75% and that as the water temperature rises, the efficiency falls. At a water temperature of around 60˚C in bright sunshine the efficiency will be about 45%. The overall daily efficiency is usually about 30% to 40% of the total solar energy input. However, the efficiency can vary enormously, depending on the way the system is set up. It will also vary from day to day.

T_{panel} will usually lie between 7˚C and 75˚C while in New Zealand, $T_{ambient}$ ranges from around 6˚C to 25˚C in most cases. From this, it is clear that the performance of the panels is most sensitive to the temperature to which the hot water cylinder is set, rather than the geographic location of the installation (this point is amplified in the discussion on the Sola60™ H300 system below). The difference in the average solar radiation between Auckland and Invercargill, for example, is about 0.5 kWh/m^2 per day, or about 10%. Economic studies indicate that after allowing for ambient air temperature and other factors, the cost of solar water heating may increase by 10% for southern centres compared with Auckland. The effectiveness of solar water heating is not as sensitive to location as is passive solar space heating (refer to Chapter 2, "Solar House Design", Section 2.3).

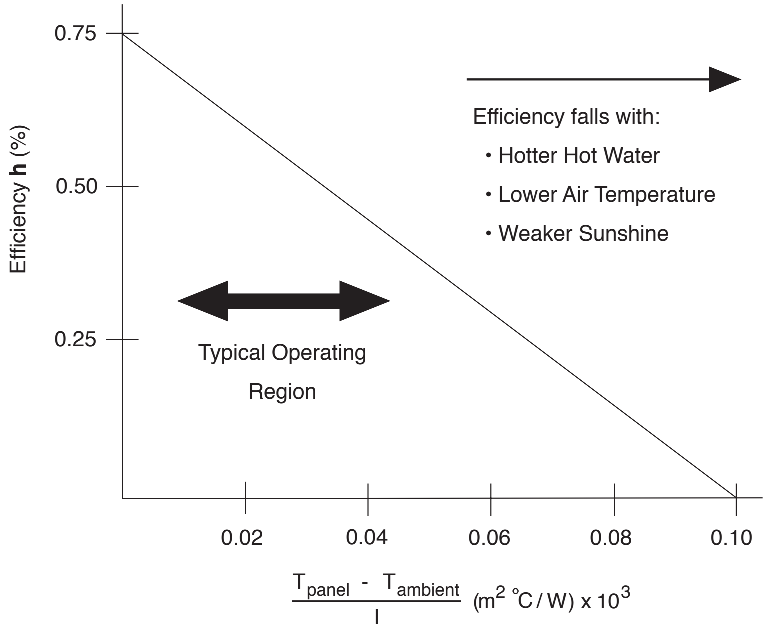


Figure 12.1: Typical solar panel performance

Glazing and insulating a panel has a similar effect to raising the ambient temperature. When a system is operating only a few degrees above ambient, as is the case in pool heating, then poor insulation and lack of glazing are not serious disadvantages. Solar heating for swimming pools, therefore, usually uses simpler and less expensive equipment than for domestic water heating This is fortunate because the major losses from pools are due to evaporation and in order to make up for these losses one ideally needs a pool heating collector with an area equal to at least half of that of the pool (a pool cover would reduce the collector area).

Panel Design Options

As mentioned above, the typical domestic solar water heater consists of a flat plate, tube-on-sheet device, as shown in Figure 12.2. The performance of such a collector depends, among other things, on the nature of the absorber surface, on the absorber sheet materials and on the spacing of the risers.

A matt black surface has a high absorptivity for all wavelengths of radiation and is the most commonly used surface. Until recently, the absorber sheet was made of copper to provide high thermal conductivity from the sheet to the risers. In a typical all-copper unit, the spacing of the risers was about 150 mm. With the increase in the price of copper, various attempts have been made to avoid the use of copper for the absorber sheet. The most common replacement is aluminium, which has a conductivity about half of that of copper. If this is the only change made, it would result in a drop in the collector performance. To offset this one must either put the risers closer together or use thicker material. Both of these measures will result in a partial loss of the cost advantage gained by the change.

More recently, aluminium with a selective surface coating has become available. Such a surface has a high absorptivity for radiation of solar frequencies but a low emissivity at its own temperature. This means that for a given input intensity, the surface will operate at a higher temperature than a simple matt black surface. This higher operating temperature offsets the lower conductivity of aluminium and helps to maintain the performance of the panel.

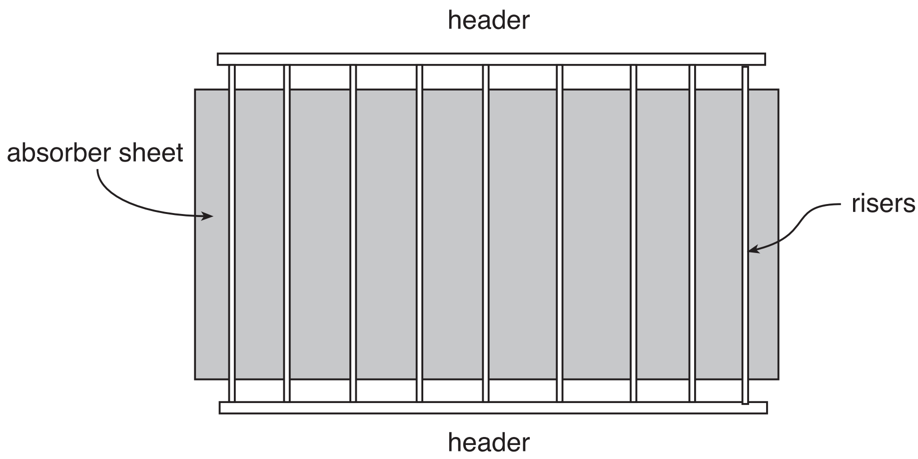


Figure 12.2: Flat plate tube-on-sheet collector (Williamson, 1994)

The other problem with copper tube-on-aluminium-sheet collectors is that of obtaining a good thermal bond between the aluminium sheet and the copper tube. This is a design area in which different solutions have been adopted by different manufacturers of aluminium/copper collectors. With one solution, thin aluminium and copper sheets are roll-bonded together in such a way that the copper can be hydraulically expanded to form a tube which is integrally bonded to aluminium fins.

A different approach has been taken by another manufacturer, who uses the heat-pipe effect to obtain a high thermal conductivity using steel, a material that has only one tenth of the thermal conductivity of copper. A heat pipe in its simplest form consists of a tube from which all air has been removed and into which a small quantity of volatile liquid has been introduced. Such a device conducts by evaporation and condensation of the enclosed liquid and has a thermal conductivity that is nearly independent of the material of which the tube is made. A simple steel or copper heat pipe can have an effective conductivity more than a thousand times that of solid copper. The Thermocell Heatsheet™ solar collector uses a flat plate version of a heat pipe as shown in Figure 12.3.

Because of the high conductivity of the "sheet" it is only necessary to have a simple water carrying copper tube heat exchanger soldered on near the top edge of the absorber. The working fluid in the Thermocell panel is a hydrocarbon, the steel does not come into contact with water, and therefore there is no internal corrosion problem.

An alternative approach that uses steel has been adopted by another manufacturer. Copper tubing can be placed inside a steel collector. The collector is filled with degassed water and possibly anti-corrosion agents and antifreeze. The water to be heated is circulated through the copper tubing. This sets up convection currents in the sealed water within the collector, thus creating an efficient mechanism for heat transfer from the steel collector surface to the copper tubing.

Yet another collector that has recently made its appearance on the market is made entirely of plastic. An absorber sheet and storage tank are integrally moulded of heavyweight polyethylene. Cold water enters the absorber at its lowest point and as it is heated, it convects upwards into the storage tank. The tank and the back of the absorber are insulated with polyurethane foam and the front of the absorber is covered with a clear acrylic sheet. The design eliminates corrosion, reduces the risk of leaks and its slight flexibility provides an inherent protection against frost. The current model was designed for freestanding operation with no provision for electrical boosting. In this form it would be suitable only as a preheater to a conventional hot water system in New Zealand.

There is now a range of well-designed robust well performing relatively low-cost solar collectors on the market. The detailed features of some of these systems are discussed later in this chapter.

Solar System Layout

The complete solar water-heating system consists of the collectors, the storage and the means by which these are coupled. There are two major arrangements of solar water heating system in common use: thermosyphon systems and pump circulated systems.

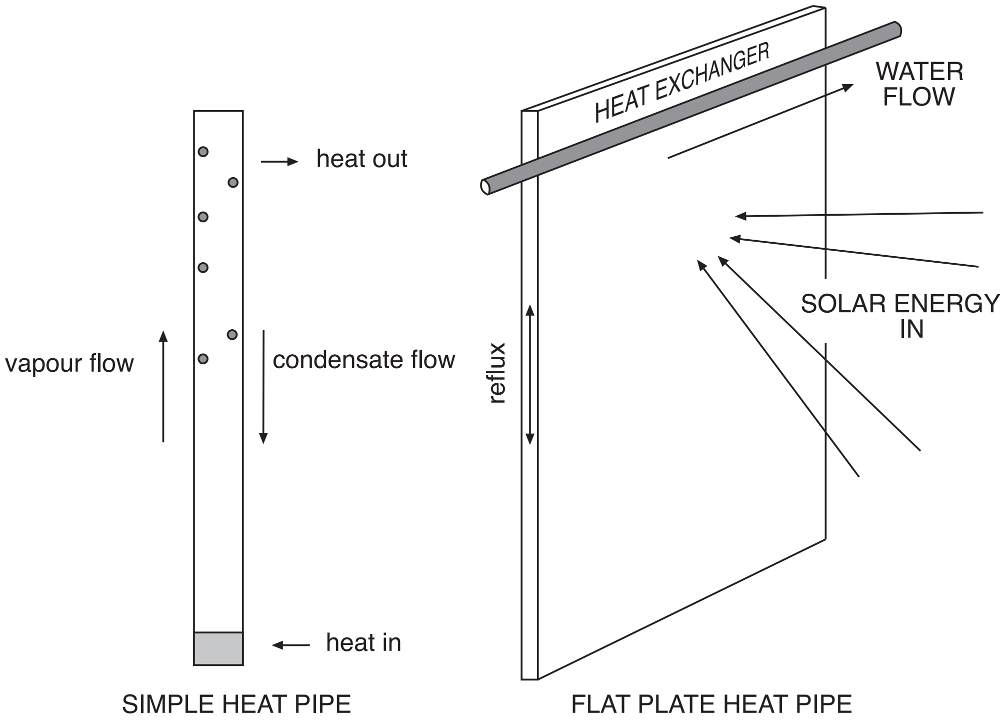


Figure 12.3: Flat plate heat pipe collector (Williamson, 1994)

Thermosyphon systems use the temperature of the water in the collector to provide the circulation, as shown in Figure 12.4. They have the advantage that there is no auxiliary equipment and no parasitic energy required to operate the system. The disadvantage of the thermosyphon arrangement is that there are tight constraints on the geometry of the system. In particular, the cylinder must be above the collector panels and there must be a continuous rise in the pipes connecting the collector and the cylinder.

In frost-prone areas it is necessary to provide protection from freezing of the pipe-work and panels. This is usually done either by incorporating a "frost valve" that opens at a degree or two above freezing and allows a small flow of warm water through the panels, which is then dumped to waste, or by using other controls that stop water flowing to and from the cylinder and then drain the pipe and collector when freezing is imminent. The deliberate or inadvertent circulation of warm water at night means loss of heat, however, and a lower overall conversion efficiency. Some collectors can expand to accommodate freezing (flexible plastic collectors) or are not completely filled with water so that icing causes no damage. Another approach is to drain the system during the "frost season", although this strategy is risky.

Another frost protection measure involves using an intermediate fluid, such as water with antifreeze added. The intermediate fluid is operated on a closed circuit and is used to heat the water actually consumed (an intermediate fluid may also be used to reduce corrosion or blockage problems where water quality is poor).

The pump circulated system illustrated in Figure 12.5, on the other hand, uses a circulating pump and a control unit to sense the cylinder and the collector temperatures so that the pump can be turned on when there is hot water to be collected from the panel. A pump circulated system can be used with any relative positions of the collectors and the cylinder, and the frost protection can be implemented using the temperature sensor on the panel to turn the pump on when the panel temperature falls below a critical value.

The most common method of mounting solar collectors is externally on a north-facing roof surface. In general any orientation between north-east and north-west will provide adequate performance. Orienting a panel at 330˚ (30˚ west of north) will cause negligible change in efficiency. Moving a panel 30˚ east of north will result in a 5% to 10% drop in efficiency. The ideal angle for mounting is the latitude angle, but again, good performance can be obtained at angles in the range latitude plus or minus 20 degrees. Angles flatter than latitude improve summer performance and steeper angles improve winter performance. For solar collectors used in conjunction with wetbacks the flatter angles are preferred as the wetback will be in use during winter.

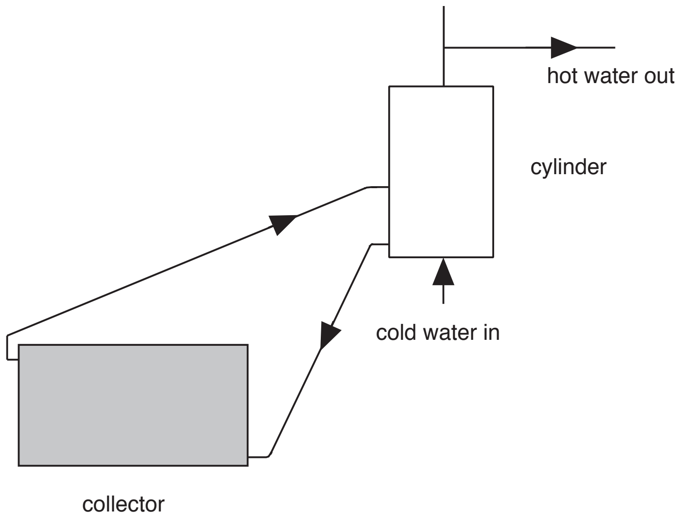


Figure 12.4: Thermosyphon layout (Williamson, 1994)

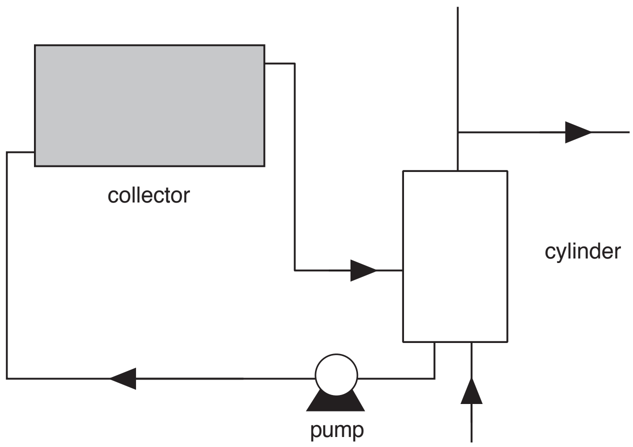


Figure 12.5: Pump circulated system

Panel Mounting Considerations

Recently, there has been a move in some systems towards installing the collectors integrally as part of the building structure. The photographs in Figure 12.6 show how integrally mounted panels can fit into a roof line and provide an aesthetically pleasing result. As well as being architecturally more acceptable than externally mounted systems, integral fitting has a number of small but significant technical advantages over external mounting. Integrally mounting panels means there is no exposed plumbing and more insulation can be placed underneath the collector (consumer preference for thin collectors when placed on an existing roof can mean sub-optimal panel insulation). Another advantage is that only one surface is exposed to wind and the other elements.

System Size — Load Match

Performance figures obtained in the early 1980s for the electricity savings achieved by domestic solar water heaters ranged from 200 to 700 kWh per square metre per year, with the best unit giving from 400 to 700 kWh per square metre per year, depending on the temperature setting of the cylinder thermostat (50˚C to 70˚C). Most modern equipment can be expected to have similar performance. For example, recent demonstration tests of the Sola60™ H300, under the auspices of EECA (EECA, 1994), showed solar contributions of over

600 kWh per m^2. A figure of about 550 kWh per square metre per year is frequently assumed for a cylinder thermostat setting of 60˚C. This, in turn, leads to the frequently quoted 2200 kWh per year for a four square metre installation.

Sizing solar systems to loads will depend on many factors, but some rules of thumb have been developed for the New Zealand circumstances. Generally, around 0.75 to 1.25 m^2 of collector will be needed per household member. Larger households (e.g. six persons) need less area per person. The storage tank needs to match the water demands and collector area. Generally, around 60 litres per square metre of collector will provide a satisfactory service. A typical configuration for a family of six would be 4.5 m^2 of collector and 270 litres of storage with electrical backup.

Figure 12.6(a): Integrally mounted solar panels

Figure 12.6(b): Integrally mounted solar panels

Backup Heating Options

Most solar collectors may be used with the various low-pressure hot water systems and with medium- and mains-pressure cylinders. Some manufacturers of mains-pressure cylinders express concern about having solar water heaters attached to their cylinders for fear that the temperatures might exceed the safe limit for the ceramic lining of the cylinder. For this reason, there are relatively few mains pressure solar water heating systems in New Zealand.

Electrical backup capacity is typically 2 to 3 kW. Backup heater controls and/or the location of the thermostat in the storage tank can have a significant impact on the solar contribution to water heating. Timing the backup so that it comes on in the evening will increase the solar contribution. If the backup is allowed to operate during the day, then placing the thermostat high in a storage tank increases the opportunity for solar preheating of water after morning draw-off of hot water.

Solar water heaters may also be used in conjunction with wood burners equipped with wetback water heaters. In this application, care must be taken to ensure that the plumbing arrangements for the two heating systems are kept separate. They can share the same storage tank but should have separate circulation systems. Cross connections can lead to unsatisfactory operation of either or both systems. Generally, the solar panel is angled for best summer performance and the wetback relied on in winter. Electric backup is usually provided for both wetback and solar operation.

Solar water heaters can also be used to preheat water for storage and instantaneous natural gas and instantaneous electric heaters.

12.4 Solar Heating Case Studies

Overview

This section presents a brief description of the technical features of four different types of solar water heaters:

- Sola60™ H300 Collector;
- Solco Rotomoulded Collector/Tank;
- Thermocell Heatsheet™ Collector; and
- Energy Roof Solar Heater.

The Sola60™ H300 unit demonstrates the advances that can be made on the conventional copper flat-plate tube-on-sheet collector. The Solco unit has the appearance of a standard thermosyphon system, but uses rotomoulded plastic to obtain an easily manufactured, cheap and robust system. At the time of writing, the unit was not marketed in New Zealand, but it is available ex-Australia. It has a number of features that may make it particularly suited to use north of Auckland or in the South Pacific.

Thermocell's Heatsheet™ system represents a radical departure from conventional materials and heat transfer mechanisms, the advantage being an economical and reliable unit. It uses a steel sheet and heat pipe transfer system.

Finally, a built-in solar roofing unit trialed in Norway but clearly applicable to New Zealand is described.

Sola60™ H300 Collector

Introduction

A new product from Sola60 Ltd incorporates sophisticated technology to achieve a cost-effective and high-performing solar hot water system. The H300 system is designed to suit a family of six and has a 4.5 m^2 collector and 270 litre storage tank. A smaller system, the H200, is suitable for a family of four.

The collector is a metal plate and riser system but has a number of special features described below. The system can operate via a thermosyphon in which the hot water circulates through the collector and then into a storage cylinder located slightly above the collector. It can also be retrofitted to existing hot water cylinders using a 25 W pump to circulate water.

The Sola60™ 300 has been tested in New Zealand as part of a joint demonstration project with the EECA. A demonstration project profile brochure is available from EECA.

Technical Features

The heat collecting surface of the H300 unit is an aluminium fin with a selective surface coating. This coating is stable, has a long life and provides a high absorbance (92%) and low emittance (12%) of infrared radiation.

The absorbed heat is trapped and shielded from convection losses by a transparent cover over the collector plate. A flexible plastic glazing film is used which has a transmittance of 92% which is about 5% better than standard glass. The collector plate is insulated on the back and sides with 30 mm of high density polyurethane foam.

The absorbed heat is conducted through the aluminium fins to a number of copper water tubes. These copper tubes are metallurgically bonded to the aluminium to improve heat transfer efficiency. The use of copper avoids corrosion problems. Figure 12.7 shows the main features of the collector plate and risers.

Electric boosting would normally be 2 to 3 kW. The life of the system is estimated to be in the order of 20 years.

Energy Yield and Economics

Test results indicate that the Sola60™ H300 system can provide annual electricity savings in the order of 3000 kWh, or over 60% of the typical hot water system requirement in a typical Auckland home (EECA, 1994). Like all solar systems the H300 unit's performance depends on the level of solar radiation and the relative draw-off temperature. For solar levels above 6 kWh/m^2/day (a bright summer's day), the unit will provide all household hot water requirements. Figure 12.8 shows how the solar fraction of the energy input to water heating varies with incident sunlight.

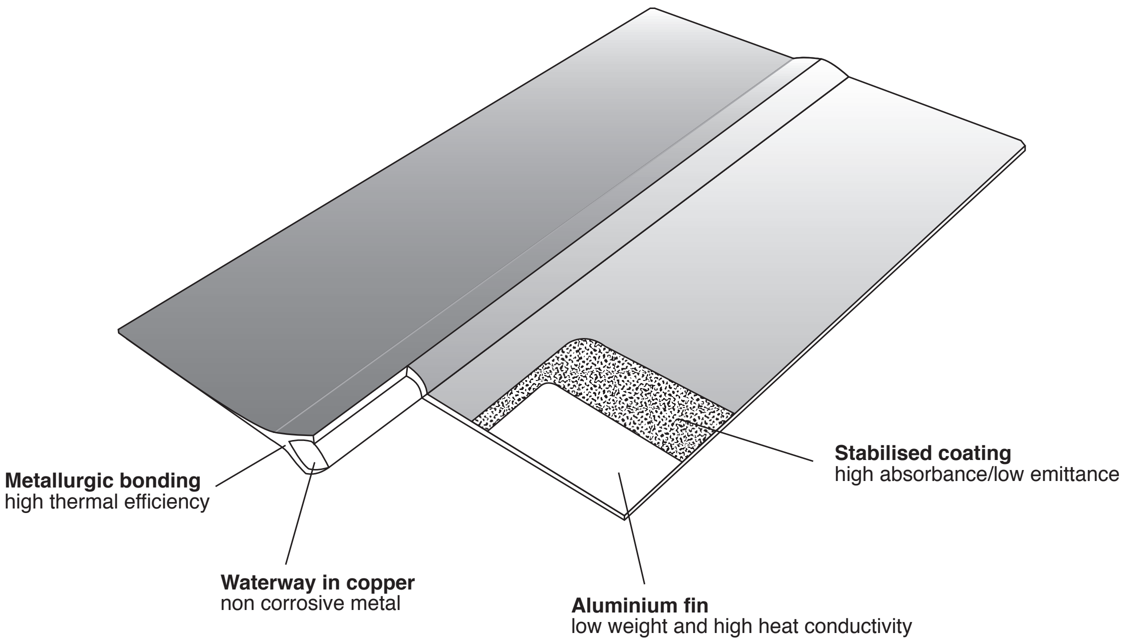


Figure 12.7: Sola60™ absorber

The curves in Figure 12.8 show that as the storage temperature is lowered, the solar contribution goes up. Reducing the storage temperature from 60˚C to 50˚C will increase the power savings by over 25%, or nearly 1000 kWh per year. Savings could be increased further if the electric heating element was switched off on bright days (this could be done automatically) or the electric boost was confined to night rate operation. Concerns over legionella bacteria lie behind the current interpretation of the Building Code that thermostats must be set to at least 60˚C. Some overseas studies suggest, however, that 45˚C is sufficient (but at this level the water may not be warm enough for dishwashing).

Table 12.2 shows the predicted change in performance of the H300 unit in Wellington and Christchurch. While the solar contribution falls in these more southerly areas, solar water heating can still substantially reduce electricity requirements. Table 12.3 shows the economics of the system for the three main centres. The payback periods and rates of return (ROI) on investment are quite attractive. The lifecycle costs of around 10c/kWh are very competitive with all electric heating.

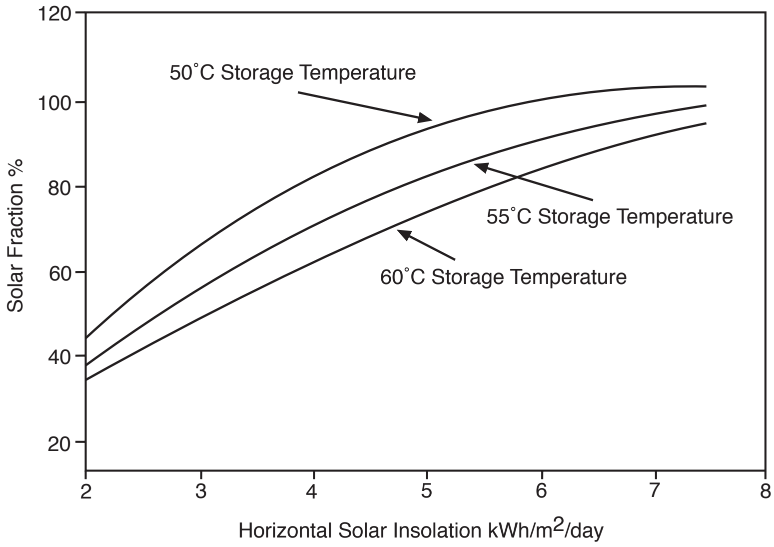


Figure 12.8: Sola60™ H300 performance curves

City	COP	Solar Contribution kWh/year	Purchased Energy kWh/year	Solar Fraction %
50˚C STORAGE TEMPERATURE				
Auckland	2.5	3100	1400	67
Wellington	1.9	2800	1900	57
Christchurch	1.9	2800	2000	56
60˚C STORAGE TEMPERATURE				
Auckland	1.8	3100	2500	54
Wellington	1.5	2800	3100	46
Christchurch	1.5	2800	3200	46

Table 12.2: Performance of Sola60™ system

City	Payback Period years	ROI %
Auckland	6.5	15.4
Wellington	7.1	14.1
Christchurch	7.0	14.3

Table 12.3: Economics of a Sola60™ system

Discussion

The Sola60™ H300 uses a well established solar collector configuration, but provides good performance through a combination of a number of technical details and competitive system pricing. The tests results for the H300 emphasise the need to manage electric boosting carefully to get the best solar contribution. They also raise the issue of the appropriate storage temperature for domestic hot water supply.

Solco Rotomoulded-Integral Unit

Description

The system developed by Birwick March Ltd is marketed in Australia under the name Sunsaver Solar Water System (referred to here by its alternative name, the Solco system). The system consists of an integral storage tank and collector plate produced from polyethylene by rotational moulding technology. The storage tank is a horizontal cylinder at the top end of the unit. Cold water enters the inclined collector plate at its lowest point and rises as it is heated to enter the storage tank. The unit is similar in appearance to a conventional solar water heater but has a number of special features that make for cost effective performance. Its main limitation is that it operates on low pressure water supply. With a mains water supply, the correct pressure can be achieved by using a header tank or pressure reducing valve.

The collector part of the unit does not have conventional water risers separated by absorption and conducting surfaces. Instead it is basically an open space, a top and bottom surface connected at regular intervals by surface dimples. The collector is fully flooded with water, with negligible obstruction to water flow. This mitigates clogging problems associated with dirty or mineralised water supplies. Furthermore, the volume of water combined with the ability of the polyethylene to expand means the unit is unaffected by frost conditions. The fabrication method means there are no joints or gaskets or metal components in contact with water, which almost eliminates corrosion problems and the risk of leaks.

The storage tank and the base of the collector are covered in polyurethane insulation. A high light transmitting acrylic sheet covers the collector plate and reduces heat loss from air convection. The collector provides a large contact area between the water and the heated polyethylene surface sheet. The design of the storage tank means most of the hot water can be drawn off without mixing with incoming cold water. These features combine to create a unit that is as efficient overall as an expensive high quality copper unit. The unitary construction and cheap materials of the Solco unit reduces manufacturing costs compared with a conventional solar water heater.

Figure 12.9 shows the main structural features of the rotomoulded unit while Figure 12.10 shows how the unit fits into a low pressure water supply system.

Application

With a storage tank capacity of 185 litres, the Solco system is scaled to residential use. It was originally designed to be an unboosted, freestanding hot water system primarily for tropical or subtropical climates. In this form, in may only be applicable in Auckland and Northland. The system is now being developed as a preheater for conventionally fuelled storage heaters. It may also prove suitable for providing preheated water for instantaneous gas and electric heaters. The unit can be fitted with an electric booster to raise the outlet temperature on cloudy days or when there is heavy draw-off from storage. As a package with a booster or as a preheater, the unit is likely to find economic applications in the temperate regions of New Zealand.

The rotomoulding concept and the general design of the Solco system could be developed further to better suit New Zealand conditions. The current collector area of 1.65 m^2 may be too small to provide optimal performance under New Zealand conditions. Increasing the volume of the storage tank and the thickness of the collector insulation may also be useful given the ambient air temperatures and wind velocities experienced in New Zealand.

Thermocell System

Description

A Christchurch firm, Thermocell, has developed a highly efficient solar water heater that avoids the need for expensive materials such as large copper sheets. In a normal solar water heater, water comes in a header at the bottom, is heated as it travels up through risers and is then taken off the top header. Solar energy is absorbed by sheets of material and conducted to the risers. The more risers needed, the greater the fabrication expenses. Copper is often used as its heat conductivity is good. It is expensive, though, and the distance between risers is still no greater than 15 cms.

In theory, at least, if a highly conductive material could be found, the input and output headers and risers could be done away with. Only a single pipe would be needed. Thermocell has achieved such a high conductivity by going away from metals to using a variant of the heat pipe. Sunlight energy absorbed by the collector plate vapourises a working fluid in the flat-plate heat pipe. The vapour conducts the energy to the water pipe and then condenses as it heats the water. The condensate runs down the back of the collector plate and the cycle starts again. Figure 12.3, presented earlier, illustrates the heat pipe mechanism applied to a solar panel.

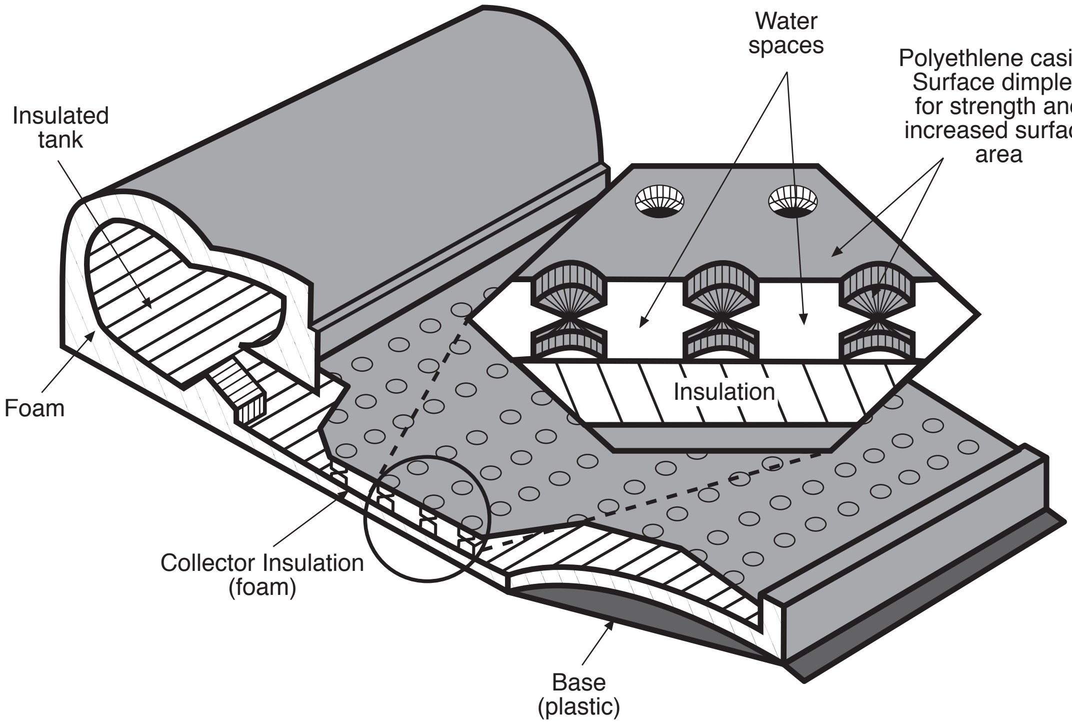


Figure 12.9: Solco collector/storage tank

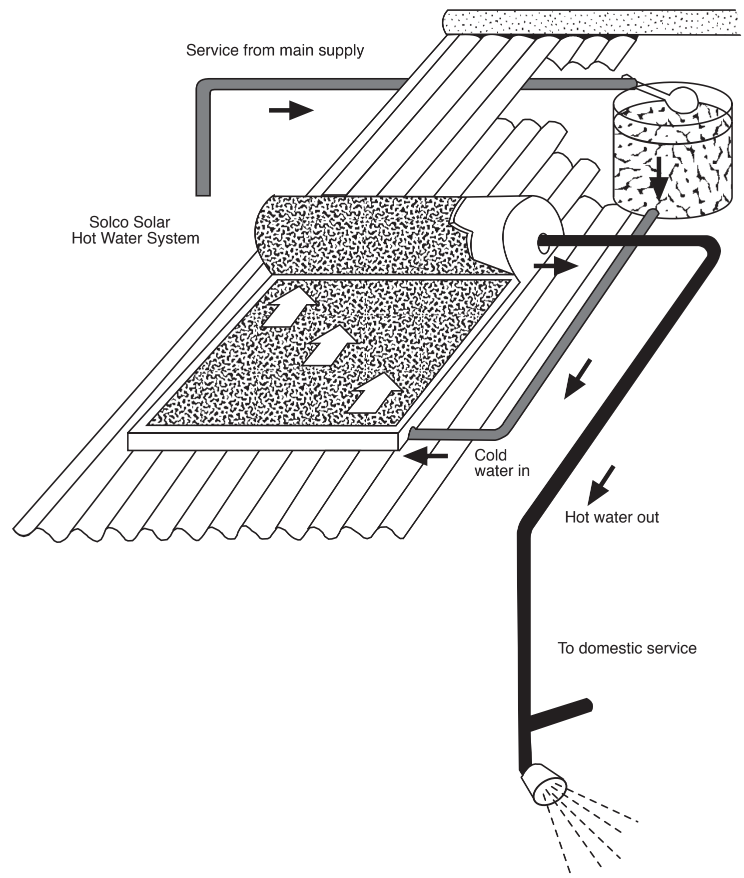


Figure 12.10: Complete Solco system

The conductivity of this system is 1000 times that of solid copper. The collector plate can be built of a wide range of materials. Test have shown that a lightweight sheet made of steel matched the performance of an all copper conventional tube-on-sheet collector. Heat exchange and cost considerations decreed that instead of one tube, the heat exchanger should consist of a triple run of small-bore copper tube. Figure 12.11 shows the placement of this copper tube on a Heatsheet™ flat plate heat pipe.

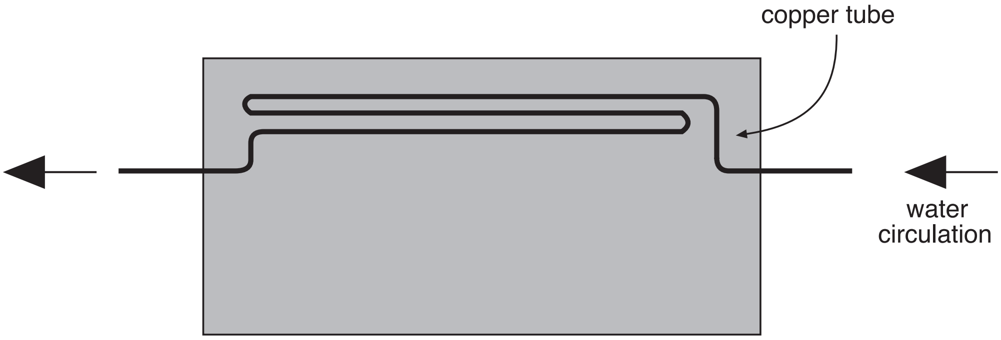


Figure 12.11: Heat exchange between Heatsheet™ heat pipe and copper water tube (Williamson, 1994)

Practical considerations also indicated that the collector plates should be around 0.75 m^2. The plates are light (8 kg) and robust and can easily be configured into series or parallel connected banks. In the conventional form, the absorbers are mounted in a galvanised steel case with fibreglass insulation and glass glazing. The finished panel weighs 20 kg. Four to six panels would normally be used in a residential solar water heating system.

The collector plates are quite thin (around 1 cm) and are designed to fit under glass that is flush with the house roofline. In this position, they can be covered in glass or plastic, which becomes part of the roof. Insulation, such as fibreglass batts, can be placed under the collector plates to reduce heat losses. The system can operate under full mains pressure or low pressure. The storage tank can be located on ground floor level (usually in the water cupboard location). An electronic unit controls the energy collection and frost protection functions of the circulating pump.

Because the collectors can be built into the roof, they are not obtrusive and do not detract from architectural lines. Figure 12.6(a), presented earlier, shows a home constructed in Christchurch by Southpower Ltd using Thermocell solar panels placed integrally in the roof. The overall system space and visual impact are barely discernible from those for a standard electric hot water heater. These features provide a number of architectural and retrofit advantages.

Application

The Thermocell system of special collector plates, remote storage and controls provides considerable flexibility. The system can be scaled to different hot water loads. High and low pressure water supply can be accommodated. Frost protection can be provided, and the collectors are inherently less vulnerable to this problem anyway. The collectors can be integrated with architectural rooflines, etc. The system is New Zealand designed for New Zealand conditions.

Energy Roof Systems

Introduction

The Energy Roof System has been installed on a number of buildings in Norway since 1991. The most recent trial was a 100 m^2 collector mounted as part of a roof in one of the Olympic villages in Lillehammer. This collector was constructed as a totally integrated part of the roof and designed to preheat water for the building's hot water supply. The roof in question was oriented south-east and had a shallow 27° slope. The collector was connected to a 2000-litre storage tank. The system delivered useful energy even when snow was lying on the roof.

The Energy Roof system is shown in Figure 12.12. It follows the basic principles of most solar water systems. Water is stored in an insulated tank, and a pump delivers water to the top of the collector, which then flows back to the tank under gravity. The pump operates as long as the temperature of water in the collector is higher than the water in the bottom of the tank. When the pump stops, the water in the collector flows back to the tank. If the tank is located above the lower edge of the Energy Roof, then an additional pump will be needed to effect water return.

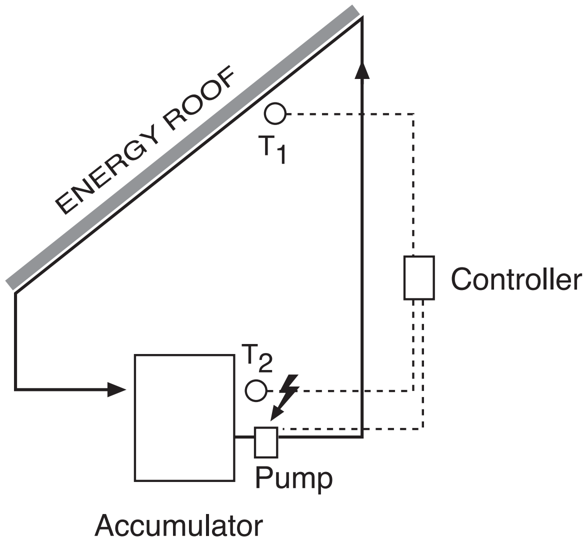


Figure 12.12: The Energy Roof System

Technical Features

The Energy Roof is designed to:

- be integrated with the building;
- use water as the energy transport medium;
- operate at atmospheric pressure; and
- be protected against freezing by structural features.

As shown in Figure 12.13, the Energy Roof is a sandwich construction with the following sheets:

- underside insulation — Rockwool or similar;
- corrugated aluminium bottom transfer panel;
- flat aluminium top solar absorption panel; and
- transparent polycarbonate front plate and spacers.

The aluminium plates are glued together and the dimensions of the corrugated panel are chosen to create a self-supporting roof plate. As a result, each Energy Roof module can substitute for an equal area of conventional roofing elements.

Each module has distribution and collector channels built into the top and bottom respectively. Heat from the absorber plate is transported by conduction down the side walls of each of the corrugated channels and is then transferred through the base of the channels to the water flow; water does not fill the corrugated channels. It has been found that the water flow needed to obtain a suitable cooling effect is roughly 1 litre/min-m^2.

With this low flow, the water forms meander-like oscillating strings, as illustrated in Figure 12.14. This flow pattern gives a significantly better heat transfer than a linear pattern would otherwise provide. The overall efficiency of the system, as shown in Figure 12.15, is as good as or better than most conventional flat-plate collectors (compare Figure 12.15 with Figure 12.1).

Energy Yield and Economics

The energy output from the solar system depends on its size and water demand, timing and acceptable delivery temperature. For most applications in Europe, the output per m^2 collector is considered to be 250 to 400 kWh/year (CADDET, 1994). Data for New Zealand conditions are not available, but the performance would probably be at the top of the range or better. Assuming a real interest rate of 5% and 15 years payback time, the energy cost of the solar energy delivered by the Energy Roof system in Europe falls between NZ$ 0.10 to 0.20 per kWh depending on site and system specific conditions.

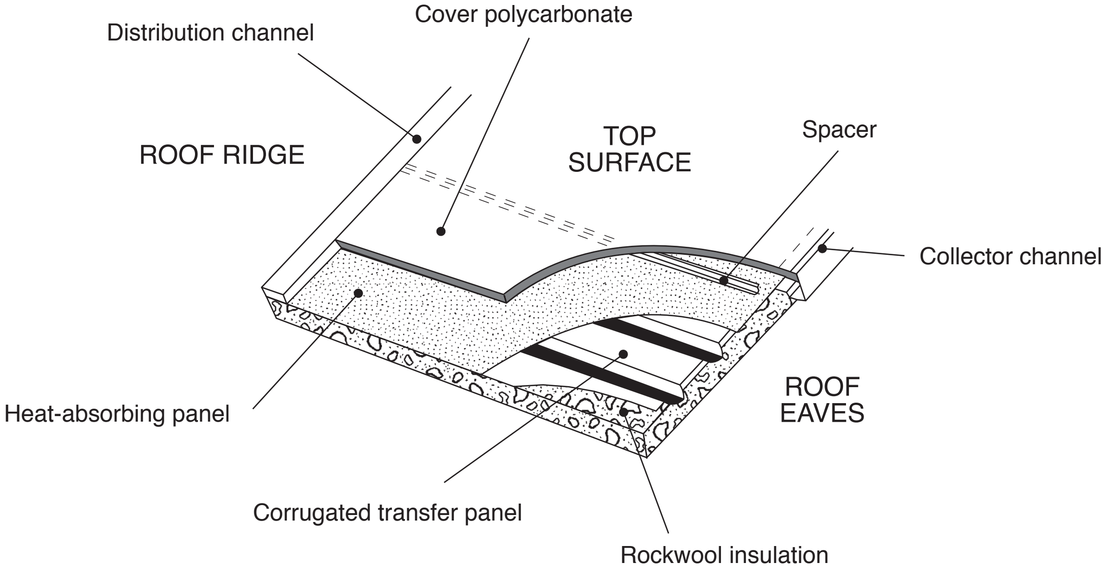


Figure 12.13: Energy Roof System — construction

Discussion

Energy Roof systems have a wide range of advantages. They are relatively easy to construct — this can be done on site. They completely replace the normal roofing elements, saving materials, and they blend in with the remaining roof profiles. Energy roof systems have conversion efficiencies similar to other solar water heating collectors. The systems can be scaled, subject to suitable roof areas and orientations, to meet different loads; they are suitable for both domestic and institutional (e.g. resthome) applications. The cost of water from Energy Roof systems is likely to be competitive with other forms of solar water heating in New Zealand.

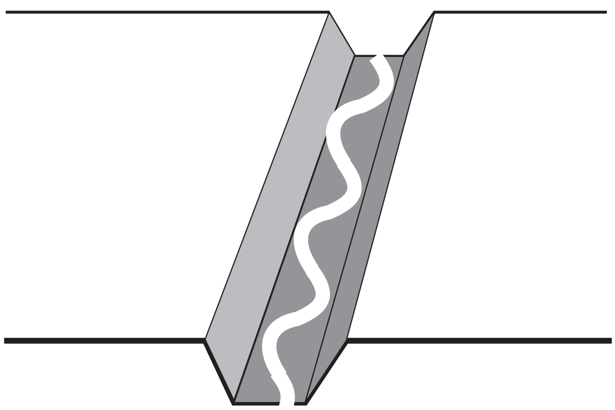


Figure 12.14: Flow pattern of water down the corrugated channel in the Energy Roof

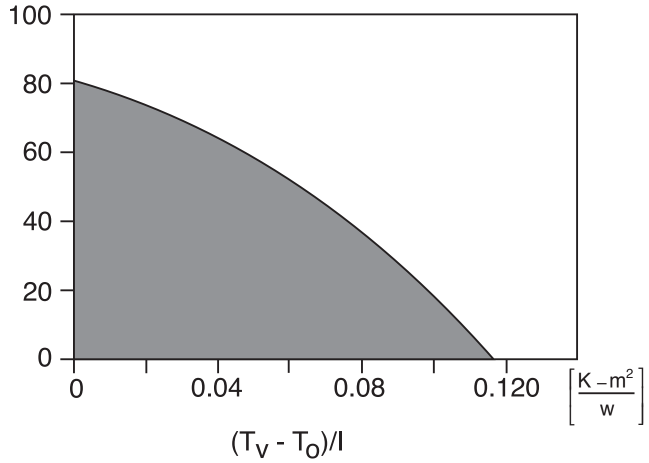


Figure 12.15: Energy efficiency curve for the Energy Roof System (I is the incident radiation intensity and T_v - T_o is the temperature difference between the air surrounding the collector and the average water temperature inside it)

High Temperature Solar

Special collectors are being developed to provide high temperature steam (around 180˚C) for residential applications (Electricity Commission, 1991). The heat obtained can be stored as water under pressure in an accumulator. Surface heat losses from the accumulator can be used for active space heating. The stored heat can be used for more than just hot water supplies for the bathroom, laundry and kitchen. Its high temperature makes it suitable for cooking and, via technologies such as absorption heat pumps, it can be used to supply air conditioning and refrigeration.

With normal flat-plate collectors, the thermal balance between incoming and outgoing radiation usually occurs at around 80˚C, or higher if selective surfaces and good insulation are in place. Convection and conduction losses become a problem when high temperature applications are attempted. This problem can be dealt with by evacuating the space between the glass cover and the absorber surface. The easiest evacuated shape to manufacture is a tube. The resulting limitations of a small collector surface can be overcome by placing the tube in a concentrating device, such as a parabolic mirror, that can be in the form of a trough. The collection surface can be a metal tube with a selective surface through which water is pumped and converted to steam (synthetic oil could be heated instead of water-steam). Alternatively, the tube could be a heat pipe with heat exchange to the water (or oil) taking place at one end of the tube.

A trial is underway using a set of parabolic reflectors-evacuated tube collectors on a house in Sydney. Preliminary indications are that the system can provide up to 90% of the winter season thermal loads (space and water heating). High temperature solar technology has been proven for power generation and cogeneration in California. The Cambelltown District Hospital in Sydney has a parabolic solar system to provide part of its process heat requirements. This technology may find future application in sunnier parts of New Zealand.

References

EECA (1994). *Environmentally Friendly Hot Water*, Energy-Wise Demonstration Project Profile, Project Summary 40, Energy Efficiency and Conservation Authority, Wellington.

Electricity Commission (1991). "Solar Thermal" in *New and Alternative Technologies for Electricity Generation*, Electricity Commission of New South Wales.

CADDETT (1994). *Olympic Solar Energy at Lillehammer*, G Rekstad, Renewable Energy Newsletter Issue 3/94, CADDETT/IEA.

Williamson, A. G. (1994). Figures provided to CAE from Thermocell Ltd. (Christchurch) publications.

Chapter 13
Opportunities in Domestic Lighting

13.1 Introduction

This chapter discusses the technology available to increase the efficiency of domestic lighting and begins by describing the technologies available to improve the efficiency of light sources.

The incandescent gas-filled tungsten filament bulb is almost the universal light technology in New Zealand homes at present. The most promising technology for the improvement of domestic lighting efficiency is the replacement of the incandescent gas filled tungsten filament bulb with fluorescent light sources, which are about five times more efficient. Technologies other than fluorescent sources that can be used to improve the efficiency of domestic light sources are also discussed in this chapter.

Various estimates have been made of the potential for improving the energy efficiency of lighting in New Zealand homes. For example, a reduction of 80% was proposed in “Energy Management and the Greenhouse Effect” (Ministry of Commerce, 1991). However, the potential predicted by these estimates has not yet been realised. This chapter provides some insights into why this is the case and makes recommendations for future action.

A model house is used to obtain a fresh idea of the savings that could accrue if the new technologies were applied. The economics of efficient lighting, the technical problems of utilising the new technologies and ways to overcome these problems are discussed.

Luminaires currently in use in New Zealand are described and the scope for, and the barriers to, introducing new technologies are outlined. Barriers include perceived cost effectiveness, practical limitations of the lighting stock, aesthetic perceptions of the householder and lack of information. It is hoped that this chapter will go some way to rectifying this latter barrier. Recommendations that could lead to overcoming the barriers are made.

It should be noted that this chapter is essentially a desktop study. It has not been possible to undertake surveys or research to provide firm data or information that would allow reliable predictions of total energy savings that could be made or the time to achieve them. Rather, the need for such research is identified.

13.2 Fluorescent Lamps

Energy efficient fluorescent lamps are not widely used in New Zealand. Fluorescent lamps depend on an electric current or discharge occurring in a low pressure mixture of gases contained in a glass tube. Most of the energy radiated by the discharge is in the ultraviolet spectrum and not be seen by the human eye. Special “phosphors” that absorb the ultra violet light and re-emit light in the visible spectrum are coated on the inside of the tube. The nature of these phosphors has a considerable effect on the efficiency and the light quality produced.

Fluorescent technology has been available for many years but until recently was considered unsuitable for domestic use. This was because of low light quality (such as colour rendering), limitations due to tube shape, inappropriate light outputs for domestic situations and problems with flicker.

A recent national promotion of the Philips PLCE compact fluorescent lamp achieved sales of 50,000 units and was considered a success by the promoters. However, this represents only one lamp per 22 households. Wright and Baines (1986) estimated that fewer than 5% of residential light sources were fluorescent in 1985, based on anecdotal evidence. Reliable data is still not available but it seems likely that the penetration of fluorescent technology is still very low.

In recent years, several technological advances have occurred that can be expected to make fluorescent light sources more acceptable to consumers. Solutions that have been found to past problems are discussed below.

Light Quality

The phosphors originally used to produce the light from fluorescent tubes gave rise to a high colour temperature (cold or harsh) light of low colour rendering index. This latter, less obvious parameter, which is the measure of the ability of a light source to separate colours, is probably more important than the colour temperature in determining the perceived quality of light. Colours seen under a light source of low colour rendering index merge together and appear to be viewed through a grey haze. Both conventional and tungsten halogen incandescent light sources, to which the fluorescent light sources were compared in the past, have warm colour temperatures and "perfect" colour rendering. Special fluorescent tubes that overcame these problems were available at that time, but their efficiencies are low and they were expensive.

Recently, "triphosphor" lamps have been developed with new phosphors that overcome the problems of light quality mentioned above. Colour temperatures matching those of incandescent lamps are now available and, more importantly, the colour rendering indices are much improved and approach those of incandescent sources. This performance is obtained at efficiencies of approximately five times and with bulb lifetimes of up to eight times those of incandescent light sources.

Tube Shape and Output

In recent years, "compact" fluorescent lamps (CFLs) of lower wattages and folded tube shapes have been developed. These compact fluorescent lamps are designed to have light outputs and physical dimensions approaching those of the incandescent sources they could replace. These include a particular type of compact fluorescent lamp that is designed for retrofitting into existing luminaires (sometimes referred to as a retort CFL).

Flicker

Flicker during startup still occurs with some lamp types. Economic analysis later in this chapter suggests that fluorescent lamps should only be used in areas of long hours of use; consequently, startup flicker will not often be experienced. Electronic starter switches that do not suffer from this problem are available, but they are more expensive than the common glow switch type. High frequency electronic ballasts do not suffer from starting flicker and have the additional advantage that the fluorescent lamp operates more efficiently and with a complete absence of stroboscopic effect. However, they are more expensive than with a wire wound ballast.

Flicker during operation can be caused by a starter switch or tube that has reached the end of its life and should be replaced. When incandescent lamps require replacement, they stop working altogether.

Early fluorescent tubes also caused disconcerting stroboscopic effects because the light pulsated at twice the frequency of the alternating current. This effect has largely been eliminated in modern tubes by using phosphors that exhibit "afterglow", which means that light continues to be emitted as the current changes direction.

Conclusions

Despite the technological advances outlined above, the fact remains that the nature of a fluorescent lamp is fundamentally different to that of an incandescent lamp. The surface of the tube is many thousands of times larger and less intense than the filament of an incandescent lamp. This makes fluorescent lamps much less suited to display, special effect and floodlighting applications. Another difference arises from the fundamentally linear shape of the fluorescent tube as opposed to the approximately point source provided by incandescent lamps and indeed the predecessors of the incandescent bulb, such as the candle, the oil lamp and the gas mantle. Folding the arc tube only partially overcomes this difference.

Another difference between conventional incandescent lamps and fluorescent lamps is the need for the latter to work in conjunction with special control gear or ballasts, which are required to control the operation of the lamp. Accommodation of this ballast must be considered in the design of luminaires.

Lamp size characteristics have a major effect on luminaire design. This issue is discussed in Section 13.6. If greater use of CFLs in New Zealand homes is to be promoted, then the challenge lies in changing peoples' perceptions of what is an aesthetically acceptable luminaire. This is a particularly difficult problem in the domestic sector, where tradition often plays a major role in lighting decisions. The change of thinking is of significantly greater magnitude than was necessary when the incandescent bulb was introduced because incandescent lighting was readily perceived as an extension of flame-sourced light (e.g. candles).

13.3 Tungsten Halogen Incandescent Sources

Normal incandescent light bulbs have a tungsten filament that is heated by the electric current to a high enough temperature to emit light. Tungsten is lost from the filament over time until the filament breaks and the lamp reaches the end of its life. A gas filling is used to slow the loss of tungsten.

A more recent development that prolongs the life of the tungsten filament is to introduce some halogen gas into the bulb. The bulb must run at high temperature. To achieve this, it is much smaller than an ordinary incandescent bulb and is made of quartz. Tungsten halogen lamps are sometimes called quartz halogen lamps. One type has a special dichroic reflector that does not reflect the substantial infrared portion of the lamp's output and is often referred to as a "dichroic".

Tungsten halogen sources can have longer lives than ordinary bulbs, can have higher efficiencies or a trade-off between the two. A comparison of light outputs of common gas-filled incandescent lamps and tungsten halogen equivalents on the market (Table 13.1) show that the tungsten halogen lamps offer up to 60% higher efficiency (compare the top lumens/watt value for a QT12 with a GLS 100 as shown in Table 13.1). As can be seen from Table 13.1, however, relative efficiencies depend on the lamp types being compared and the higher relative efficiencies only occur in a few cases. Any energy cost savings accruing from the use of tungsten halogen lamps are more than offset by their high replacement cost.

The main advantage of tungsten halogen light sources lies in the fact that the filament is very compact, which means concentrated light beams can be produced. Such tight beam control makes tungsten halogen light sources suitable for display lighting, special effect lighting and floodlighting applications, but confers no special benefit for general illumination. The widely held belief that tungsten halogen light sources are "energy efficient" appears to arise from a comparison of achievable beam intensities rather than total luminous output. This latter parameter is the only one relevant to general illumination.

13.4 Other Light Sources and Technologies

Efficient discharge light sources other than fluorescent tubes are used in commercial and industrial applications. These have not been considered for domestic use as they do not show large gains in efficiency over fluorescent tubes in the sizes suitable for domestic use and suffer from such drawbacks as poor colour, poor colour rendering and long restart time if switched on when hot.

Advances in these technologies could see them become more suitable for use in domestic situations in the future, but the degree of penetration expected by the year 2000 would be small.

Apart from changing the light source, there are other means, some real and others misconstrued, to improve lighting efficiency. Using dimmers, for example, is often assumed to be energy efficient but in practice is rarely so. Using effective light fittings and making sure lights are only used when needed do help to improve efficiency. These points are elaborated below.

Dimmers

Dimmers are not a light source but rather devices that modify the power consumption and light output of light sources. Both conventional and tungsten halogen lamps can be fitted with low-cost electronic dimmers that reduce lamp voltage and consequently energy consumption. The efficacy of an incandescent lamp reduces sharply with voltage, so a dimmed lamp cannot be considered to be running efficiently. If lower light levels are required for long periods, then it would be more energy efficient to use a lower wattage bulb. Dimmers are a convenient way of changing the light levels in multiple use areas such as might be required in the dining area for the occasional formal dinner but cannot be viewed as a way of increasing energy efficiency.

Fluorescent lamps cannot be dimmed by these simple dimmers. Dimming fluorescent controllers are available and, although they do maintain reasonable lamp efficacy at low light outputs they are probably too expensive to be considered by most householders.

Tungsten				**Tungsten Halogen**			
	Power Consumed Watts	Luminous Flux (Lumens)	Efficacy Lumens/ Watt		Power Consumed Watts	Luminous Flux (Lumens)	Efficacy Lumens/ Watts
Bare Lamps				**Bare Lamps**			
GLS 60W	60	730	12	QT12	58 (1)	950/1000	16/17
GLS 100W	100	1380	14	QT12	112	2300/2500	20/22
				QT18	100	1350/1400	13.5/14
GLS 150W	150	2220	15	QT18	150	2250/2400	15/16
Reflector Lamps				**Reflector Lamps**			
R63	60	650	11	QR-CB51	58 (1)	940	16
PAR38	60	600	10	QR70	58 (1)	550	9.5

(1) Transformer losses included

Table 13.1: Comparison of tungsten and tungsten halogen sources

Luminaire Efficiency

Domestic luminaires (the light fitting) are often not designed with luminous efficiency in mind. Consequently improved luminaire design or selection offers considerable scope for increased lighting efficiency. This increased efficiency can be used to increase lighting levels or energy may be saved by the use of smaller light sources. Luminaire efficiency is discussed further in Section 13.5, which categorises the luminaires used in domestic installations.

The efficiency of the luminaire is often dependant on the appropriate light source being used. This is also discussed in Section 13.5.

Hours of Use

The simplest way of improving lighting efficiency is to reduce the hours of use by switching off unneeded lights. This is an operational rather than a technical consideration and so is beyond the scope of this chapter. However technology can be used to reduce unnecessary operation of lighting.

One example is provided by the use of infrared detectors that switch on outdoor lighting only when people are detected in the lit area. Similar detectors are available to control lights in individual rooms. Solar switches, which turn lights off when daylight reaches a certain value, and timers can also be used to ensure that lights are on only when required.

13.5 Potential Energy Savings and Economics

Wright and Baines (1986) devised a model house as the basis for estimating domestic lighting use. Their results are shown in the first three columns of Table 13.2. There is no information available to improve or update these figures. It is noted that average total household energy demand has increased since 1985, but what percentage of this increase is due to lighting is not known.

Lighting Group	Use Per Day (Hours)	Model (kWh/Year)	Alternative (kWh/Year)
Kitchen Area	6	275 I	55 F
Other Main Living Area	4	240 I	48 F
Remaining Household	Less than 4	185 I	185 I
Total Household		700	288
Percentage Saved			59%

I = Incandescent
F = Fluorescent

Table 13.2: Annual electricity use by lights in 1985

If the lighting in the two areas illuminated for the longest period of time is replaced with some type of fluorescent lighting, which is assumed to consume only 20% of the energy of the incandescent bulbs, a saving of nearly 60% of lighting energy is achieved (last column of Table 13.2). This saving involves replacing fewer than half of the total number of bulbs in the model house.

It is interesting to calculate the lighting levels in the model house. Assuming a living area of 3.6 x 4.5 metres and a utilisation factor of 0.3, the lighting level would average 50 lux. This is minimal. In a 3.0 x 2.6 kitchen, the average lighting level would be 65 lux. Good placement of the luminaires could mean that the light level on the working surface is higher than this. However, the minimum level recommended in NZS 6703:1984 for such working surfaces is 200 lux and 500 lux would be desirable. While these are averaged figures, it is apparent that many people have lighting levels that are less than optimal. It is interesting to speculate whether this is from choice or because many have inherited the lighting design and find it too complicated or costly to upgrade.

The householder could well choose to upgrade light levels given the ease of doing this when replacing incandescent lighting with fluorescent lighting. In fact, the extra capital cost of higher wattage equipment is usually only marginal.

Economics of the Savings

Figure 13.1 shows the cost structure of running ordinary light bulbs and CFLs. Total costs are made up of capital and running costs.

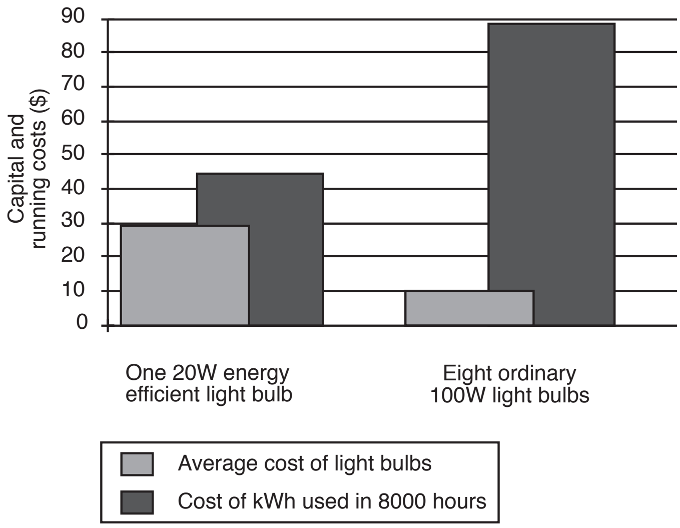


Figure 13.1: The ordinary light bulb versus the energy efficient light bulb

If one 100 W incandescent lamp used for four hours a day is replaced by a 20 W retrofit CFL, then the simple payback will be 2.3 years. This assumes that a 20 W retrofit CFL costs $30 and lasts 8000 hr, incandescent bulbs cost about $1 and last 1000 hr and that electricity costs 10c per kWh. Given the potential problems with installation and the appearance of the retrofit CFL discussed later, this may not be strong enough incentive. In fact, even on Chatham Island where electricity is 40c a unit, these negative factors have meant that there was strong resistance to such retrofits.

Trade prices are used in this chapter where it is hard to establish a retail market price. Mass marketing could mean that retail prices lower than trade price would be possible once demand is established. For example, the trade price of a standard 100 W GLS incandescent lamp is $1.80 compared with the supermarket price of 95c. Another example is provided by the promotion of the Philips PLCE lamp (a retrofit CFL) referred to in Section 13.2. These lamps were effectively sold for $30 during the promotion, whereas the trade price was over $40.

For low volume items, retail prices are usually higher than trade prices. For instance, luminaires can be marked up by as much as 30% when they are retailed in lighting showrooms. Trade prices do not include GST, which has to be added to the retail price.

Greater production volumes can also lower trade prices. By way of demonstration it is worth comparing the price of an 18 W CFL, at about $20, with that of a 600 mm 18 W triphosphor tubular fluorescent lamp at a price of $8. The performance of the lamps is similar, but the tubular fluorescent is a mature product produced in much greater quantities than the CFL.

Simple payback analysis is used here for simplicity. However, the relevance of simple payback or any other economic analysis in the case of discretionary or household investment is open to question (the concept of payback and its limitations are discussed further in Chapter 15). Consumers make purchasing decisions based on their own perceived value of the alternatives, and this evaluation is seldom objective. For instance, a consumer may decide to upgrade a lampholder and shade to a purpose-built fluorescent luminaire if it was felt this would primarily improve the home and use less energy at the same time, even if s/he was aware that the payback period was unattractive. Similar non-quantifiable evaluations are often made when a consumer is faced with a choice such as that between an "economy" and a "deluxe" product. Conversely, a good financial return will not ensure a purchase if the consumer sees negative aspects to the investment, such as poor appearance that can result when retrofitting CFLs.

There is considerable scope for further study of what may motivate consumers to buy energy efficient products and how this motivation may be achieved; however, such study is beyond the scope of this chapter.

13.6 Technical Problems of Introducing Fluorescent Technology

Fluorescent technology is a viable way of improving the efficiency of domestic lighting in New Zealand. There are, however, practical problems to its widespread application. This section discusses the options for, and identifies some of the difficulties of, introducing fluorescent lamps into domestic buildings.

Retrofitted Compact Fluorescent Lamps In Existing Luminaries

Most attempts to improve the efficiency of domestic lighting to date have involved using retrofit CFLs. These retrofit CFLs either have an integral ballast or come with a separate plug-in ballast. In both cases, the lamp-ballast combination or the separate ballast are designed to plug directly into the socket used for conventional incandescent lamps. The separate ballast design is more economical because at the end of the lamp life, a new lamp can be fitted for under half the cost of a new integral unit.

Retrofit CFLs come in two fundamental configurations. The most common is the "parallel" configuration, where the tubes lie parallel to the axis of the lampholder. The best known example would be the Philips PLCE lamp. The alternative is the "perpendicular" configuration where the tubes lie perpendicular to the lamp holder axis. The best known example of this design is the Thorn 10 W and 16 W 2D lamp with plug-in ballast. The configuration of the tubes relative to the lampholder can have a big effect on luminaire efficiency.

A third type of CFL, which always comes with an integral ballast, has a diffusing plastic cover and is intended to be used as a self-contained luminaire by plugging it into a simple lampholder. It can also be used in an existing luminaire provided it fits and gives the desired light output.

The penetration of retrofitted CFLs has not been great, as demonstrated by the promotion reported earlier. There would appear to be three reasons for this. Firstly these plug in compact lamps cost considerably more than the incandescent bulbs they replace, and domestic consumers are very sensitive to first cost.

Secondly and perhaps not so widely recognised, is the problem that because of the differences in the nature of the incandescent and tungsten light sources discussed above, there are few luminaires in the average home that are suitable for retrofit CFLs. The larger size of the retrofit CFL is exacerbated by the need to interpose the ballast between the incandescent socket and the lamp, which often means the lamp will not fit in the luminaire. Even where the compact lamp physically fits, the light distribution is often compromised and the higher lighting efficiency that is being sought is not fully realised. In order to obtain a satisfactory result the householder may have to experiment with a variety of CFLs.

Thirdly, the appearance of many incandescent luminaires when fitted with retrofit CFLs is unacceptable to many people. This is discussed further in Section 13.7.

It has been suggested that luminaires suitable for both incandescent and compact lamps be manufactured. However, because of the differences in the nature of the light sources, such designs would in most cases be a compromise solution.

A further problem that can arise when attempting to increase domestic lighting efficiency by retrofitting CFLs is that when the lamp comes to the end of its life, the householder is faced with another large capital outlay and the chances are that he or she will revert to the use of incandescent bulbs if faced with financial constraints at that time.

Finally, there have been concerns that the power factor and harmonics generated by retrofit CFLs could become a problem on the supply network if their use becomes widespread. Given the limitations discussed above, this possibility does not seem very likely in domestic installations. However, some retrofit CFLs, such as the Smart Lamp and the Condor, which have superior power factor and generate lower harmonic currents, are available.

It should be also pointed out that New Zealand Electrical Code of Practice No. 36 "Harmonic Levels" (NZECP 36:1993) specifies the maximum harmonic levels that a consumer may generate as seen at the "point of common coupling" between the consumer and any other consumer. This would include all harmonics generated by compact fluorescent lamps as well as other common household appliances such as televisions, dimmers, speed controlled motors and so on. Should harmonic levels rise to unacceptable levels on residential distribution networks, NZECP 36 would empower the network operator to require the consumer to provide a solution.

There is no equivalent code of practice controlling the power factor of the energy drawn by a consumer's installation. In the past, electrical supply authorities have laid down requirements for minimum power factors but have seldom been required to take action in the case of domestic installations.

A table showing the characteristics of some retrofit CFLs is included as Attachment 1 and a discussion of the potential for harmonic generation in household distribution systems is included as Attachment 2.

Purpose Built Fluorescent Luminaires

Most of the problems associated with retrofitted CFLs can be overcome by using purpose-built fluorescent luminaires. However the differences between fluorescent and incandescent light sources mean that the form or appearance of the luminaire may be different.

Luminaires are currently available that can accommodate CFLs similar to the separate ballast type used for retrofitting. Other luminaires use larger CFLs intended only for use in purpose-built fittings.

The initial cost of these purpose built luminaries can be low. For instance, one 21 W utilitarian luminaire is available, complete with lamp, at a trade price of $77, only slightly more than some of the more expensive retrofit CFLs. It is of interest to note that the incandescent equivalent of this fitting only costs marginally less, at $64.

An increasingly wide range of luminaires in different price brackets and for different purposes is being manufactured. Unfortunately, almost none of these are seen at discount lighting shops and the collection available at the more upmarket showrooms is usually small. Needless to say purpose build fluorescent luminaires do not suffer from compatibility problems with CFLs. The light distribution and luminaire efficiency is also optimised for the CFL source.

Lamp replacement cost, at about $20, is lower than for the integral ballast-type retrofit CFLs. As discussed above, this price could be expected to fall as CFLs become more widely used. Because incandescent bulbs cannot be used, the energy saving technology is locked in.

Finally, the problems posed by power factor and harmonics can easily be solved with a purpose-built fluorescent luminaire because they usually have wire wound ballasts and a power factor capacitor is supplied as standard or can easily be specified. Purpose-built luminaires to take regular tubular fluorescent lamps are also available and can be very economical in some circumstances. Tubular fluorescent lamps with phosphors identical to those used in CFLs are available, and all the advantages discussed above apply.

13.7 Barriers to More Efficient Lighting

This section discusses the lighting stock currently in use in New Zealand homes and the types of luminaires being installed. This information helps to gain a picture of typical "real life" barriers that exist with respect to the introduction of new technologies.

In the course of writing this section it was not possible to carry out a survey of a representative sample of homes to gain accurate data on existing lighting equipment. Indicative information was obtained by visiting domestic lighting showrooms both to see the lighting solutions on display and to interview the sales staff in order to discover what lighting solutions were available to householders. This information was compared with personal observations made in a number of homes.

Luminaires used in New Zealand homes were classified into three categories according to the financial circumstances and the aesthetic preferences of the occupants. The practical difficulties inherent in applying new technologies to each of these categories are explored below.

Utilitarian

Utilitarian lighting schemes are characterised by being of low first cost. A typical utilitarian installation would consist of a bulb suspended from the centre of the ceiling with or without a shade. The shade is intended to direct the light downwards more effectively than the ceiling would and to reduce glare by avoiding direct light from the lamp entering the eye and by increasing the apparent size of the light source.

However, if the shade is other than white on the inside, it will not achieve these results and in fact could give inferior results to those obtained by relying on a light-coloured ceiling. This is an example of an opportunity to increase luminaire efficiency simply by modifying or replacing the shade.

A parallel configuration retrofit CFL will physically fit in most situations of this type, but owing to the fact that the lamp is so long that it often hangs below the shade and because light is largely emitted horizontally, performance suffers because light is directed onto the walls rather than the working plane. This problem can be overcome by using a deep, trumpet-shaped shade designed to work with the particular CFL. In this case, the shade must be white to maintain luminaire efficiency, but it must be noted that such shades are not commonly available.

A perpendicular configuration integral compact fluorescent lamp will give better results in this case, even without a shade. However with a shade, problems can occur because, again, the ballast can push the luminous centre of the lamp down to where the shade is not functioning as intended. This problem can sometimes be overcome by dropping the shade down to rest on the ballast. In the larger sizes, the width of the folded tube could be too great, leading to its fouling the shade. Once again, a purpose-built shade would overcome these problems. A CFL with an integral plastic cover, with or without a shade, could also be used in this situation.

A problem with retrofit CFLs is posed by the fact that until recently the largest size is only equivalent to a 100 W lamp. In a utilitarian installation, there is likely to be only one luminaire in the room and a 150 W equivalent could be required to achieve reasonable light levels. This is particularly relevant because task lights are not often part of utilitarian lighting schemes. It is understood that larger retrofit CFLs equivalent to 150 W incandescent bulbs will soon be available.

As an alternative, one could consider a 28 W purpose-made fluorescent luminaire (equivalent to around 140 W) at a trade price of $110. The payback would be longer but, as discussed above, the consumer could see other benefits in this approach.

A luminaire often used in utilitarian situations is provided by covering the light source with a spherical paper "Chinese Lantern" shade. This approach is low cost and gives soft, glare-free light. Either type of integral compact lamp can be adapted to this shade with little difficulty. Unfortunately, the light transmission of the Chinese lantern is not good leading to low overall efficiency. However, the energy consumption will be reduced compared with that of an incandescent lamp under the same shade.

The utilitarian approach gives poor results in a kitchen as the person at the sink stands in his or her own light. This problem is often observed. Moving the luminaire over the sink bench is a simple remedy.

Despite the problems identified above, it can be seen that it is relatively easy to use CFLs in utilitarian lighting schemes. However, if we assume that many householders have utilitarian lighting schemes from necessity, it is unlikely that capital will be available for the purchase of either retrofit CFLs or purpose-built luminaries. In some cases, such as council flats, the landlords may be prepared to invest the capital required as a public service.

Traditional

Traditional lighting schemes are characterised by luminaries that are designed to look like the traditional oil lamps and chandeliers that were in use before electricity was used for lighting. Main room lighting is often provided by a multi-light source "chandelier", which still has the glass covers originally placed to prevent the drafts from disturbing the flame. In some cases, these covers are frosted to increase the apparent size of the light source and so reduce glare. In others, they are also coloured for aesthetic reasons. Sometimes special incandescent lamps designed to look like candle flames are used. Styled bracket lamps are often used on the walls to augment the main light source. Table and standard lamps are often used for accent and task lighting.

Unfortunately, traditional lighting luminaires tend to be designed for effect rather than luminous efficiency. Often the colour of the inside of conical shades is not white but rather determined by the colour of the fabric used to cover it. The glass covers mentioned above can lead to light loss and are usually too short to cover a retrofitted compact lamp. The aesthetics of such a retrofit are dubious as the whole thrust behind the traditional approach is to make the light sources look like candles or oil lamp wicks. This illusion is not fostered by a compact fluorescent lamp, particularly if it is protruding from the cover.

It is likely that not many householders owning traditional lighting systems would want to install retrofit CFLs. Incorporation of CFLs in new installations would be dependent on the availability of purpose-built traditional fluorescent luminaires. There are few of these on the market now. It is a challenge for designers to devise traditional luminaires that use CFLs.

Modern

Modern lighting schemes are characterised by luminaires designed to suit the requirements of the light source and the lighting effect required. For this reason, there is more scope for introducing fluorescent light sources. There is also more scope available to achieve different lighting effects in a modern lighting scheme.

Modern lighting luminaires include diffusers, downlighters, uplighters, spotlights, task lights, cornice or pelmet lights and so on. The purpose of all these fitting types in a domestic situation is to provide a soft background light for general illumination while at the same time providing sufficient light on task areas and accenting objects such as pictures. The accent lighting is also there to provide contact with the background lighting. Current fashion calls for extremes of accent lighting with little background lighting to soften the effect. However, the increasing use of uplighters and pelmet lighting may indicate that a change back to a more balanced approach is occurring.

Diffusing luminaires or "diffusers" produce even, overall light levels that can be used alone or as a background to task and accent lighting. There is a wide range available that accept either CFLs or standard tubular fluorescents. Diffusing luminaires can be designed to be very efficient.

Uplighters are used to produce very soft background light. Modern domestic uplighters are a form of bracket or standard lamp and often use 200 W or 300 W tungsten halogen light sources. This form of luminaire is not suitable for a low intensity fluorescent light source.

Another form of uplighting that is increasing in popularity is that provided by pelmet or cornice lighting. In these cases, low-cost conventional fluorescent fittings using low cost tubes can be concealed in such a way that light is shone upwards onto the ceiling. This alternative would be much more efficient than the tungsten halogen uplighter. Unfortunately uplighting schemes are generally a less energy efficient way of providing diffused light than the diffusing luminaires.

Downlighters are often recessed into the ceiling and can vary from a wide beam type giving soft lighting through to a narrow beam for accent or special effect fitting. The wide beam types are available with CFLs but for the reasons discussed earlier, the narrow beam types (accent lighting) are limited to incandescent light sources.

Problems have been reported with some downlighters allowing excessive ventilation into the roof space with consequent heat loss. This problem is most marked in the case of some cheap luminaires where the lampholder is mounted on a simple stirrup and no house or reflector is used. The problem is exacerbated if the correct lamp is not used as the clearance between the lamp and the luminaire can be greatly increased.

These problems do not occur with the CFL downlighters as they require little ventilation and have closed reflectors as an integral part of their design.

Work being done by E Source (1993) has shown that tube wall temperatures can rise above that for optimum efficiency in unventilated CFL downlighters in commercial applications. Efficiency losses of 10% have been measured. However, where unventilated domestic CFL recessed downlights are protruding into an unheated roof space, temperature rise would not be as great as in commercial situations. On balance, in domestic situations, ventilation losses are likely to exceed lamp efficiency losses from increased temperatures (no venting case), so the use of closed reflectors is advised.

Similar efficiency losses due to burning the lamp in the base up position have been measured, but lamps are being developed that minimise this effect. These inefficiencies are of second order compared with the inefficiencies of continuing to use incandescent light sources in domestic downlighters.

Narrow spotlights, like accent downlights, can only utilise incandescent light sources. Some retrofit CFL spotlamps are available, as are some purpose-built fittings utilising CFLs, but they are not suitable for all situations as the beam has a wide spread.

Modern lighting schemes that allow the bulk of the light to be provided by fluorescent light sources could easily be devised.

13.8 Conclusions and Strategies

It is concluded that replacing incandescent bulbs with fluorescent technology is the most effective improvement that could be made to the light sources used in domestic buildings. Automatic switching schemes and more efficient luminaires would also improve efficiency, although it is not possible to quantify the benefit at a national level.

There is a realistic potential saving of 60% by using fluorescent light sources in the main living areas of New Zealand homes. This improvement cannot all be achieved by simply retrofitting CFLs as replacements for incandescent bulbs. In many cases, it will be necessary to install purpose-built fluorescent luminaires. It would appear that light levels in many New Zealand homes are marginal, particularly in the kitchen. If householders used the opportunity provided by the introduction of fluorescent light sources to increase lighting levels, then the predicted level of savings may not be realised, but a safer, more comfortable working and leisure environment would result.

Paybacks of 2.5 to 5 years seem typical in retrofit situations but can be as low as 1.6 years when comparing the initial purchase of incandescent versus fluorescent luminaries and lamps. Economic analysis is complicated by the fact that benefits other than savings in energy costs should be considered by the householder and these benefits vary according to the purchaser.

Predicting the timescale over which these savings can be realised requires further research into areas such as the normal rate of luminaire replacement, the acceptability of fluorescent alternatives, the extent to which consumer information will affect uptake of fluorescent technology and so on.

Possible Future Strategies

An extension of clause H1 of the New Zealand Building Code (NZBC) could be used as a way of achieving energy efficiency in lighting with minimum light source efficacies being required in the main living areas. However, such a regulation would intrude on people's freedom of choice in an area where aesthetics is important and so could give rise to resentment. Defining the main living areas, which could change according to the habits of the occupants, would be difficult. These problems and the move away from regulation currently being experienced would combine to suggest that regulation is not an acceptable way to achieve increased lighting efficiency.

A survey of a representative sample of homes to gain accurate data on existing lighting equipment would give a quantitative picture of the lighting stock types defined in this chapter. Research into areas such as the normal rate of luminaire replacement, the acceptability of fluorescent alternatives and the extent to which consumer information will affect uptake of energy saving technology would all help to predict the timing and magnitude of the savings to be realised. However, it is not necessary to complete this research before starting a campaign aimed at overcoming these barriers. Research into public conceptions and misconceptions regarding fluorescent lighting could be used as the basis of a national campaign to change public attitudes.

The greatest barrier to the uptake of more efficient lighting technology is the lack of knowledge on the part of the public of the potential savings and the ways of achieving them. Were this problem solved, the next obstacle is that lighting retailers do not stock a wide selection of the retrofit CFLs or purpose-built fluorescent luminaires and their staff often have little knowledge of fluorescent technology.

If these distribution problems were overcome there would still be many situations where suitable fluorescent luminaires are not available. For instance, householders wanting "traditional" style fluorescent luminaires would be poorly catered for. Even simple products such as lamp shades designed to suit retrofit CFLs are not available yet.

As in many areas where there is potential for more efficient technology to be introduced, the problem is a circular one. The householders don't know about the technology or how it can be applied, which means there is no demand. The retailers are often themselves unsure of the technology, which, combined with the lack of demand, means that they don't stock the equipment. The lack of demand also means that the manufacturers don't produce a wide range of luminaires.

To overcome these barriers and accelerate the uptake of fluorescent technology, an integrated approach is required. The first step in such an approach is provision for information and advice. Households need to be better informed about lighting options. The same can be said of architects, builders, electricians and lighting salespersons. A change in public attitude would also be encouraged by general publicity on the desirability of energy efficiency.

Alternative distribution methods, such as mail order facilities to special interest groups, would raise awareness of fluorescent solutions in the community and make retailers aware that there they face competition.

There would also be a need to encourage the production of a wider range of purpose built fluorescent luminaires that are aesthetically pleasing and meet market needs. The resources of the Polytech industrial design schools could be utilised if a fluorescent luminaire design project was included as part of the course.

EECA has arranged a competition for an energy efficient domestic-commercial accommodation luminaire. The competition is open to any designer and is being conducted in conjunction with the Illumination Engineers Society annual awards. Such activities will also help to raise the profile of fluorescent lighting by ensuring that articles appear in interior design magazines.

The technology needs to be promoted at all parts of the distribution chain. Part of this promotion should be national publicity aimed at the householder. This will be more effective if it is done in conjunction with national publicity that is designed to change public attitudes to energy efficiency.

References

E Source (1993). *High Performance CFL Downlights: the Best and the Brightest*, Tech Update TU-93-6, May 1993 by R. Sardinsky, S. Hawthorne and J. Newcome.

Ministry of Commerce (1991). *Energy Management and the Greenhouse Effect,* Wellington.

NZECP 36: 1993. *New Zealand Electrical Code of Practice for Harmonic Levels*, issued by the Office of the Chief Electrical Inspector, Energy and Resources Division, Ministry of Commerce, Wellington.

NZS 6703: 1984. *Interior Lighting Design*, Standards New Zealand, Wellington

Wright, J and J Baines (1986). *Supply Curves of Conserved Energy, The Potential of Conservation in New Zealand Houses*.

Attachment 1: Characteristics of some Retrofit CFLs

STATE ELECTRICITY COMMISSION OF VICTORIA

Test Results on Compact Fluorescent Light Globes: August - December 1991

PRODUCT BRAND	"The Smart Lamp"	"Kempthome"	PHILLIPS	OSRAM	ECONOLAMP
MODEL	(5)	(5)	PLC* Electronic	Dulux Electronic	GP - 12B
LAMP TYPE/BRAND	Tungaram FD.D 13W	Wotan D 13W/21	N/A	N/A	N/A
COUNTRY OF ORIGIN	Australia	Australia	Holland	Germany	Hong Kong
NOMINAL VOLTAGE - volts	240	240	240	240-250	240
BALLAST TYPE	Electronic	Electronic	Electronic	Electronic	Electronic
CONFIGURATION (6)	Separate	Separate	Integral	Integral	Integral
DIFFUSER	None	None	None	None	Clear Prismatic
STATED NOMINAL POWER RATING - Watts	15	15	15	11	12
MEASURED POWER WATTS (3)	15.1	14.9	15	11.0	9.9
MEASURED VA VA (3)	18.9	18.7	32.4	22.0	20.6
SUPPLY VOLTAGE VOLTS (RMS)	240	240	240	240	240
OVERALL POWER FACTOR (Watts/VA) (3)	0.80	0.80	0.46	0.50	0.48
STATED/IMPLIED LIGHT OUTPUT - Lumens	900	900	900	600	830 (4)
MEASURED LIGHT OUTPUT Lumens (3)	936	881	875	573	427
MEASURED EFFICACY Lumens Per Watts (3)	62	59	58	52.3	43.1
TIME TO REACH 80% FULL OUTPUT - Seconds (2,3)	59	41	90	71	52
TIME TO REMAIN FULLY ALIGHT - Seconds (2,3)	0.8	0.8	0.9	0.8	0.5
APPARENT COLOUR TEMPERATURE - Kelvin (3)	2625	2730	2650	2705	3165
CURRENT HARMONICS - mA/W					
Harmonics / Max Specified in AS 3134					
2nd 1.0	0.01	0.03	0.8	1.0	1.2
3rd 3.6	1.52	2.77	81	95.5	92.6
5th 2.0	1.45	1.54	83	85.8	85.1
7th 1.5	0.37	1.08	76	69.2	74.7
9th 1.0	0.21	0.85	59	54.1	61.7
11th 0.6	0.34	0.67	47	39.8	48.2
13th 0.5	0.20	0.06	37	24.2	34.2
15th 0.4	0.17	0.31	32	14.2	23.1
17th 0.4	0.01	0.03	29	8.5	13.6
19th 0.3	0.12	0.13	26	7.6	7.6
21st 0.3	0.02	0.02	-	6.6	4.6
23rd 0.3	0.02	0.07	-	4.0	5.3
DIMENSIONS (includes Lamps)					
weight - grams	130	160	85	113	170
length - mm	188	176	140	140	170
max width - mm	56	59	37	55	90

NOTES

(1) All lamps were operated in base-up position. Lamps were allowed to stabilise for 60 minutes.

(2) All lamps were aged for 100 hours before these tests were performed.

(3) Calculated MEAN for the lamps tested.

(4) Implied luminous flux value taken from AS 2325 — 1980 Table D1.

(5) These lamps were designed to comply with proposed Interim Specification for Current Harmonics.

(6) Integral lamps are built in at the time of manufacture and cannot be changed.

Attachment 2: The Impact of CFLs on Distribution Power Systems

The findings of the study carried out by Neville Watson of the University of Canterbury on the effects of compact fluorescent lamps on a distribution power system are summarised below. CFLs of the type commonly available in New Zealand, such as Philips PLCE, are assumed to be installed.

The study was specified to represent an idealised power system from the generator to the customer's main switch. The purpose of this study was to obtain a feel for the effects that a harmonic source, such as electronic ballasted fluorescent lamps, might have on a power system. Based on these findings, further studies may be warranted for particular situations.

The power system modelled consists of a model of the South Island 220 kV power system and the part of the system from the 220 kV bus at Islington to the customer switchboard. The low voltage system consists of a 300 kVA distribution transformer with eight 70 mm^2 low voltage feeders, each with eight service mains for a total of 64 customers (an after diversity maximum demand per customer (ADMD) of 4.7 kVA). The model was chosen to represent a typical generic distribution system. It should be possible (with caution) to scale the results from this study to similar systems.

The study indicates that the total harmonic distortion, as seen by the customer at the point of common coupling on the distribution system modelled, is controlled mainly by the impedance of the distribution transformer, in this case 5% on a 300 kVA base.

The results of the study also show that, for the system modelled, the total harmonic distortion at the customer's main switch, the point of common coupling, reaches the allowable limit of 5% as specified by the Harmonics Limitation Notice, at a load of 920 20 Watt lamps, or just over 14 lamps per household. This is quite a high number of lamps, probably more than could reasonably be expected to be installed. A cautious approach is warranted, however, since there may be other sources of harmonic distortion:

- There is an ever increasing number of other harmonic generating loads, such as television sets, computers, microwave ovens, hair dryers, variable speed appliances, lamp dimmers etc., which also contribute to the total harmonic distortion.
- A number of these loads, computers and television sets in particular, generate harmonics that are in phase and very similar to those generated by compact fluorescent lamps and thus have an disproportionately additive effect on the total harmonic distortion.
- Experience has shown that significant interference and other problems can be expected when the total harmonic distortion approaches 5%.
- Recent work in Canada suggests that the total harmonic distortion caused by compact fluorescent lamps is not linear with the increasing number of lamps. This is due to the fact that as the voltage distortion increases, the lamps draw even more harmonic current. This effect is very hard to model because the present simulation assumes that the lamps draw the same harmonic currents whatever the voltage distortion level.

It is possible, subject to the caution noted above, to scale the model (within a reasonable size range) to give an indication of the expected distortion levels for other ADMDs and transformer sizes. For example, scaling the model to a 200 kVA transformer with an impedance of 4.5% and 43 customers results in a maximum load of approximately 450 lamps, or 10 lamps per customer, before the total harmonic distortion reaches 5%. In areas with a lower ADMD and more customers per transformer, the number of lamps decreases proportionately. For a 200 kVA, 4.5% transformer, an ADMD of 3 kVA and 67 customers, the maximum number of lamps is only 6.7 lamps per customer. This figure tends to agree with unofficial comments from the State Electricity Commission of Victoria.

The model was also tested with a load represented by lamps that meet the proposed Australian Standard AS3134. The results of this study indicated that for the study configuration, approximately 2500 lamps were required to cause 5% total harmonic distortion. This represents 39 lamps, or over 750 Watts per customer, a load that is unlikely to be approached in practice.

Conclusions

- Many existing compact fluorescent lamps generate very high levels of harmonics. On many distribution systems, the number of lamps required to cause the total harmonic distortion to approach the maximum allowed by the Harmonics Limitation Notice, is well within the realm of possibility. This may be especially so if power conservation measures are encouraged or enforced. In the long term, it is suggested that such lamps are unacceptable.
- Lamps conforming to Australian Standard AS3134 have a much better performance and, although not ideal, should be acceptable.
- The International Electrotechnical Commission has a standard covering fluorescent ballasts for lamps over 25 W (IEC 555 Part 2).
- Work is under way on a revision of IEC 555 Part 2 to cover smaller CFLs. The initial draft of this standard includes harmonic current limitations derived from AS3134.

Chapter 14
Appliances

14.1 Introduction

This chapter covers energy efficiency of appliances other than conventional space and water heating equipment or lighting. The main appliances are refrigerators and freezers, washing machines, dryers and stoves. Other appliances with the potential to materially impact on energy use, such as dehumidifiers, are becoming more widely used in New Zealand homes.

This introduction identifies the factors likely to affect future energy use by appliances. Section 14.2 provides a brief review of the present and future trends for each major class of appliance. Section 14.3 acknowledges the main difficulties and issues involved in measuring energy efficiency of appliances. Section 14.4 attempts to quantify the potential energy efficiency improvements for a range of common appliance types. Public policy options for promoting more efficient appliances are discussed in Section 14.5. Future directions for policy are identified. It is likely that in future, minimum energy performance standards (MEPS) will be developed for appliances (including water heaters). Section 14.6 records the general principles that have been developed overseas for introducing MEPS. The final section of this chapter describes the basic methodology for determining optimum appliance performance standards.

Electronic goods, such as televisions, computers and stereo equipment are also considered in this chapter. The energy consumption of appliances in the home is not well known, though as percentages of total home energy demand, appliance use is thought to fall within the ranges shown in Table 14.1 (Collins, 1993).

Home Activity	Lower Estimate	Upper Estimate
Refrigeration	6%	10%
Cooking	6%	8%
Other	7%	11%

Table 14.1: Appliance energy use distribution estimates

Future Appliance Energy Use

Domestic (electric) appliances are, in most cases, a phenomenon of the last few decades. Today the market is more or less saturated by ranges, microwave ovens, washing machines, refrigerators and radio and TV sets. The penetration is high for freezers, clothes dryers , dishwashers, and video recorders. Other appliances, such as garbage compacters, dehumidifiers, heat pumps and air conditioners, are yet to make any significant impact in New Zealand. What happens to the national appliance energy consumption by the end of the century is a function of:

- the increase in market penetration for appliances (for refrigerators and radios this is already well over 100%);
- the rate at which existing appliances are replaced;
- whether or not the units replaced are actually taken off the grid (refrigerators, for example, often continue to be used as a spare fridge, in the garage for example);
- the type of replacement including its size and features;

- how appliances are used (an aspect that is much more significant for clothes dryers or electric ranges than for freezers, for example);
- the built-in efficiencies of the appliances; and
- the effect of public policy measures introduced to ensure, or encourage, the purchase of efficient appliances.

Data Limitations

In New Zealand, there is quite reasonable data on present generation appliance energy consumption when measured to standardised tests. There is some data on market penetration and on age distribution of the appliance population, but poor to nonexistent statistical (or even anecdotal) data on actual usage patterns of appliances. Likewise, there is a dearth of information on energy consumption in actual use in the home (or workplace) for new appliances, let alone for those perhaps 15 or more years old. This lack of information is a serious limitation when designing measures to promote energy efficiency and monitoring the results. Household surveys to obtain a cross-section of existing appliances and a manufacturer/retailer disclosure regime for major appliances (e.g. refrigerators) to track changes in the appliance population may be needed.

14.2 Future Technologies

This section discusses the present situation and likely future outlook for different types of appliance. Space does not allow coverage of all the technological innovations that could improve future energy efficiency.

Kitchen

Refrigeration

Clearly, the major change of eliminating CFCs from both refrigeration circuits and polyurethane insulation has been challenging for manufacturers. It does appear, however, that the new technologies, when they are first produced, will have efficiencies very close to those they supersede. For a variety of reasons, it is likely that future energy consumption will fall significantly:

- CFC replacement technologies are being introduced near the beginning of their efficiency optimisation curves and will undoubtedly improve;
- the overwhelming counterproductive trend (in energy consumption terms) to ever more and bigger refrigerators and freezers per household is levelling off; and
- the average model produced today is generally much more efficient than the one it replaces.

There is a great deal of work going on internationally to improve energy efficiency within the bounds of existing technology. Both incremental and step reductions should be anticipated.

There are also many alternative refrigeration and insulation technologies at the curiosity or laboratory testing stage. It is quite conceivable that one or some of these could be developed to the stage to offer energy efficiency advantages. At the moment, the only visible likely contender in this category is vacuum insulation. Meanwhile, there is a wide range of established technologies or changes to current designs that could be used to improve the energy efficiency of domestic refrigeration. These are covered thoroughly in the United States EPA report listed in the bibliography attached to this chapter.

Cooking

Induction and quartz halogen infrared elements are not new technologies, and whether they are ever likely to gain a significant market share is debatable. Smooth tops, on the other hand, now take about half the cook-top sales. Their share of the new market is not growing significantly and, in any event, the efficiencies of all these cook-top technologies are roughly similar.

Fan-assisted ovens account for about 50% of oven sales. They have the potential to save energy if used intelligently. Ovens are available on the market that use triple glass on the front door to achieve a "cool touch" surface instead of using a stream of cool air between a twin glass barrier. The triple glass approach is far more energy efficient. Microwave ovens have the potential to reduce conventional stove use, though more so from the cook-top than from the oven itself. Common cavity ovens are beginning to appear overseas. These are conventional ovens with an added microwave unit of perhaps half the power of the traditional microwave oven. Conventional heating will brown food while microwave is much more like a boiling process. The combination is quite effective in some situations and is likely to hold a significant share of the new market by the turn of the century. Again, the effect on energy consumption will be more a function of usage than of product design.

Small appliances used for cooking are discussed below.

Small Appliances

Special small appliances such as bench top ovens, toasters, rice cookers, crockpots, coffee percolators, electric fry pans, sandwich toasters and bread makers are available now. There is no data on how much of the cooking is currently being done in these devices — or how this will shift with time. Some, such as crockpots, are probably in decline. The use of others, such as rice cookers and bread makers, are expected to increase; rice cookers because of an increasing Asian population as well as the popularity of Asian-style food, and bread makers because they are easy to use and produce good bread at a lower cost to the consumer than does the supermarket alternative. With a shift in eating habits and the arrival of these small appliances, even less cooking is being done on — and particularly in — the electric range. The efficiency of these small, generally uninsulated, appliances is not usually as good as that of the conventional stove, although the conventional toaster is an efficient alternative to the oven grill. It has low thermal inertia and its energy delivery is well matched to its task. If minimum standards were introduced for some of these appliances, the situation could probably be improved.

Other small appliances, such as electric jugs, are used for water heating. It is generally much more efficient to do this when water is needed than to keep it hot continuously. "Instantaneous" water heating for the very small amount of hot water that is needed in a kitchen for the dishwasher is energy efficient, although it is unlikely that most people would be willing to dispense with the hot tap altogether and rely on a kettle or jug. Plumbed-in instantaneous water heaters serving the kitchen sink, however, could easily take an increasing market share if a suitable, appropriately-priced unit were available and effectively promoted.

Consumption is not significant for small motorised appliances such as cake mixers and electric can openers.

Dish Washing

There is slow but steady penetration of dishwashers into the market. Even 15 years ago, dishwashers were developed to the stage that they were not net energy users (the machines used about the same energy as did washing dishes in the sink). Virtually all the energy is used in heating water, with some machines utilising hot water from the domestic supply and others heating their own. Heat is also used to dry the dishes. Efficiencies are continually being improved with reduced water consumption and improved drying techniques. This process will undoubtedly continue.

Laundry

Clothes Washing

Although the Australasian energy consumption test does not recognise it, adequate washing can be done in appropriate machines with 20°C water and almost zero electrical input. Nationally, future reductions in energy consumption will come from the spread of machines with this capability and with a continuation of the existing trend for people to do more and more low temperature washing when they have machines with this capability. Because wash temperatures may still be higher than cold water out of the tap, the continuing developments to reduce water consumption will also result in reduced energy consumption.

There is scope to increase still further the water extraction rate with higher spin speeds. The current average water content in clothes taken out of Australian washing machines is estimated as 85% (around 0.9 kg of water per 1 kg of dry clothes). In New Zealand, the figure is more like 75%. Current best technology spin dryers on the market will take clothes down to about 65%. A limit of 50% may be possible, at which stage creasing becomes unacceptable. The equilibrium moisture levels for clothing in New Zealand is typically 8%. The difference between the washing machine level and equilibrium level is achieved by using a clothes line or a clothes dryer. The Australasian energy consumption standard for washing machines gives no credit for better clothes dryness. Thus using any energy to spin out more water — even though this is a much more efficient way to remove it than in a clothes dryer — is a penalty in the energy consumption testing, which carries on over to the appliance energy consumption label.

Clothes Drying

There is an efficiency variation of about 25% from best to worst between clothes dryers presently on the global market. Overdrying is hard on fabrics and wastes a significant amount of energy. The appropriate Australasian standard adds a 10% penalty to the energy consumption of machines that do not sense when clothes are dry and automatically turn off. While data on how much energy is wasted by overdrying is largely anecdotal, it is believed that the wastage with manual termination is nearer 30% than 10%. There will certainly be an increased market penetration by dryers with automatic termination devices. There will also be improvements in how effectively they work — particularly with small loads. Other measures to improve dryer performance are under consideration by manufacturers and will have a significant impact, which will be offset to some extent though by the increasing use of dryers .

Condensing clothes dryers are available overseas. These condense the water extracted from the clothes and collect it. They are more expensive than conventional dryers and in energy consumption tests they are about 3% less efficient. They do have an application, however, in situations where external venting is not practicable or when the make-up air from outside is so cold that significant household space heating energy would be lost by the external venting of a conventional dryer. Because neither of these situations is common in New Zealand, condensing dryers are never expected to be big sellers here. Condensing dryers that recover some of the latent heat, vent the dryer air outside, and supply the heat to an incoming outside air stream are also available overseas. These dryers make up for the loss of warm interior space air and provide an efficiency boost.

Microwaves are touted as the efficient clothes drying technology of the future, although whether or not it is capable of living up to this claim is rather debatable.

Leisure/Comfort

Brown Goods

With the advent of solid state electronics replacing valves, and the increased efficiency of later integrated circuits over the first transistors, the power consumption of individual appliances in general is falling quite dramatically. This increase in efficiency is likely to keep compensating for the increase in the number (and size) of appliances. There will probably be a higher penetration of TVs, videos, home computers and fax machines. Some personal computers on the market have US Energy Star energy efficiency features. The energy efficiency of PCs and laptop computers is covered under office equipment in Chapter 5 of Part 2: Commercial and Institutional Buildings. Many TVs, videos and stereos remain on standby for remote infrared control. This wastes a small amount of energy, but is popular with consumers. In the future, low energy standby may be developed.

Air Conditioning/Dehumidifiers

Conventional electric space and water heating uses resistance heating technology. Appliances based on heat pump technology (refer to Section 8.3) are gradually entering New Zealand homes.

The reverse-cycle air conditioner can both heat and cool. Often, it is primarily designed to cool and its heating COP is not optimised. Such appliances are not new, and are likely to take an increasing share of the market.

There is never a need to space cool for much of the New Zealand domestic sector, and units designed solely to space heat are likely to become more common. It is likely that the majority of these will be air-to-air because other options such as water or ground heat-to-air typically require site specific installation.

There are a variety of dehumidifiers based on the standard refrigeration or heat pump cycle, now available on the New Zealand market. Dehumidifiers are likely to become more widespread as they provide a simple means to mitigate household moisture problems. Very large and powerful models would be needed to completely handle household moisture. The small-sized portable models more likely to dominate the market could be a useful adjunct to other moisture management measures (e.g. venting kitchens, better subfloor ventilation, etc.). Dehumidifiers are further discussed in Section 6.6.

14.3 Measuring Appliance Performance

The energy demand of most appliances will be strongly influenced by the way in which they are used and operated (e.g. the number of times a refrigerator door is opened).

Measuring the energy consumption of an appliance in a way that mimics its every day use is very difficult. Ensuring that the results can be used in comparisons with other appliances now or across time is doubly difficult. Nonetheless, the starting point for any assessment of the performance of appliances has to be a standardised means of measuring energy consumption. The result will not be perfect and may create distortions, but without some form of standardised measurement system discerning trends in appliance efficiency, setting policies and measuring effectiveness takes place in a vacuum.

Appliances need to be placed into categories based on common service provision or duty requirements (e.g. different refrigerator size ranges). Testing methods need to be standardised for different appliances and the results must be reproducible. These requirements create a number of dynamic problems that need constant attention.

Appliance energy consumption tests have to deal with a range of matters and these are usually brought together in the form of algorithms (testing procedures and assessment formula). These algorithms should mimic household behaviour and appliance circumstance (e.g. the size of washing machine loads and ambient temperatures for refrigerators). The algorithms should change as user behaviour changes or as new technologies become available (e.g. moisture sensors on clothes dryers). They could also be designed to credit appliances able to accommodate a range of user differences (e.g. dryer loads) while maintaining efficiency.

Using algorithms evokes three major issues. The first concern is that the algorithms may discriminate between appliances, by favouring some feature over others, or by making assumptions about user behaviour that do not apply to all appliances in a class. Manufacturers are very sensitive to this issue.

The second concern is that no matter how well they represent user behaviour, algorithms may create some distortions. With step functions (e.g. the Australian star label system - see below) manufacturers may focus effort on appliances close to the transition to a higher score. They may also design or market for the algorithm rather than maximum energy efficiency (e.g. by encouraging the purchase of a larger refrigerator — inherent efficiency rises with size because the surface area to volume ratio falls). Poorly designed testing methods could be counterproductive. For example, virtually all dishwashers have an economy cycle designed for testing but which is almost never used at any other time. Some European models even have high capacity dish racks developed to enhance testing scores, but the machines are sold with different racks that hold fewer dishes, but are more practical to use.

The third concern relates to assessing the benefits of appliance energy policies. Energy consumption figures derived from tests based on algorithms may represent some notion of typical use. The figures may not apply to particular households. This could be a particular problem when undertaking cost benefit analysis of policy initiatives.

Australia and New Zealand share joint standards for efficiency testing and participate in the establishment of testing methods, algorithms, etc. Having a joint approach with Australia will mean some compromises due to its continental range of climates and slightly different average householder behaviour. The key lesson is to minimise any compromise and regularly review procedures to ensure that technical distortions, such as lack of recognition for a new energy saving feature, are not developing.

A dynamic system can be made to keep up with change. The scoring system for clothes dryers, for example, recognises to a degree the benefits of automatic moisture sensors and the reality that, without this technology, most people over-dry their clothes. The relationship between washing machine spin-dry ability and subsequent electric dryer energy savings may warrant better recognition. Another example might be recognition for the benefits of demand-defrost systems for refrigerators and freezers that defrost only when required.

14.4 Energy Efficiency Potential

For some types of appliances, there are significant variations in the energy efficiencies of similar models on the market. The energy consumption of 350 to 400 litre refrigerators marketed in Australia, for example, can vary from 1.4 to 2.2 kWh per annum per litre of capacity. In New Zealand, there does not appear to be a reliable public source of data on the sales of different appliances, let alone a breakdown by appliance size or other characteristics, including energy efficiency. Table 14.2 shows the energy consumption range for a selection of appliances of similar size, type and capacity sold in Australia.

Appliance Type	Most Efficient	Least Efficient	Percent Diff.
Cyclic Defrost Refrig.	700 kWh	910 kWh	30%
Frost Free Refrigerator	1130 kWh	1250 kWh	11%
Chest Freezer	380 kWh	740 kWh	95%
Dishwasher 12 pl. set.	350 kWh	590 kWh	69%
Top Load Washing Machine	555 kWh	775 kWh	40%
Clothes Dryer	683 kWh	745 kWh	9%
Air Conditioner	675 kWh	775 kWh	15%
Electric Oven	258 kWh	388 kWh	50%

Table 14.2: Annual energy consumption range — Australian appliances

There are substantial differences in the energy efficiencies of freezers, dishwashers, washing machines, ovens and hotplates (not shown). The differences for room airconditioners, frost-free refrigerators and clothes dryers are relatively small in both percentage and absolute terms. It should be noted that the most energy efficient appliances in Australia appear to perform 15% to 25% below the best comparable appliances available in the US and Europe.

The potential of measures to improve the average appliance energy efficiency is small in the short term. It is restricted by the rate of turnover of the appliance stock (probably 5% to 7.5% per annum depending on appliance type) and the likely increase in the average efficiency of appliances purchased. An idea of the overall potential of policy initiatives to improve the efficiency of New Zealand's appliance stock can be gained by making a number of optimistic assumptions:

- the percentage differences shown in Table 14.2 will persist;
- there will be no radical change in appliance numbers/use; and
- appliances will continue to consume 15% to 25% of household energy.

If policy initiatives caused everybody to purchase the most efficient appliance marketed, then there could be a 0.5% to 1% annual reduction in household energy use.

Faster, larger improvements in household energy efficiency are possible by dealing with a range of other matters:

- improving the match between appliance choice and actual needs;
- changing the type of appliance used for a given household function; and
- changing the way appliances are used, where they are located and how they are maintained.

Buying washing machines, dishwashers, refrigerators, etc., that are larger than necessary means wasted energy. Having unused butter conditioners in refrigerators, for example, is another waste of electricity. Properly operating and maintaining both new and existing appliances is important. Keeping a refrigerator radiator (the condenser unit) clean and the right distance away from a wall can reduce electricity use by 10% or more. Changing appliance operation can also save energy via reduced use (for example, avoiding the use of clothes dryers in fine weather) and more efficient use (for example, full washing machine loads).

These management and maintenance measures could lead to a substantial, relatively quick and cost effective reduction in home energy use. Sustaining the behavioural changes required is a major challenge though. The short-term potential of changing the efficiency of new appliances, on the other hand, is small. The effect of buying more efficient appliances is cumulative, however, and the potential is on going. After a ten year period, the gain might be 5% to 10%. As long as there are differences in the energy efficiency of appliances, there is potential for further improvement.

14.5 Public Policy Options

This section discusses public policy measures to improve the energy efficiency of the nation's appliance stock. It starts by noting the range of public policy options available. These options have already been closely examined in another study (Collins, 1993). The present situation in New Zealand regarding public policies and industry initiatives to encourage the development and marketing of more efficient appliances is reviewed in this section and the most promising future directions are outlined. Sections 14.6 and 14.7 describe in some detail one of the key future options: minimum energy performance standards (MEPS).

Main Policy Options

Appliance labelling and setting standards are the two most common public measures, but they are only part of a wide range of options to improve the energy efficiency of the appliance stock:

- Voluntary approaches — continue with voluntary use of the Australian labelling system or industry-government agreements on improvements;
- Compulsory labelling — most practical option would probably be adoption of the existing Australian system (and its extension to additional appliances);
- Endorsement labels — awarded if an energy efficiency standard is exceeded or an appliance is in the top X% of its class;
- Environmental Choice NZ — combine energy efficiency criteria with other environmental concerns and use the green labelling scheme;
- Set minimum standards — regulate so that appliances not coming up to the standard could not be sold;
- Reward/trade-in schemes — offer discounts to persons who purchase new appliances that exceed a given efficiency level, or give bonuses to sales staff, or offer a trade-in grant when old appliances are traded for new ones;
- Facilitate R&D — publicly fund research into more efficient appliances (e.g. through the Ministry of Research Science and Technology);
- Publicity campaigns — increase public awareness of household energy use, and let manufacturers capitalize on this in their own way;
- Marketing assistance — provide government assistance to manufacturers and retailers to market energy efficient appliances; and
- Environmental levy — increase the price of electricity to incorporate a cost for environmental impacts, future power investment, etc.

Present New Zealand Situation

Under CER, Australia and New Zealand are committed to harmonising their regulations governing products.

Institutional arrangements have been established to provide the necessary liaison and discussion to this end. A number of Australian states have compulsory labelling schemes for electrical appliances. They use a common label format and testing standards. The range of appliances covered by labelling requirements varies between the states. The main New Zealand firm manufacturing for the Australian market (Fisher and Paykel) has to label the appliances it exports to Australia.

The Australian Gas Association runs its own labelling and minimum energy efficiency scheme for gas appliances. It is, in effect, a compulsory scheme since non-labelled appliances will not be sold in association member showrooms and untested appliances cannot be fitted since the safety and efficiency tests are integrated.

Australian standards for appliances mainly deal with safety and function issues, but a few specify minimum energy performance levels (MEPS). However, the levels are so low they have no practical effect. The Australian Gas Association (AGA) has incorporated a number of MEPS into its codes.

At present, a number of electrical appliances for sale in New Zealand carry the energy efficiency labels required by Australian regulations. Similarly, some of the gas appliances in New Zealand showrooms carry the Australian Gas Association energy efficiency labels. The situation could be described as voluntary use of the Australian electricity and gas appliance labelling scheme. In fact, voluntary labelling of appliances was promoted by the government toward the end of 1988. The promotion was not sustained, however. The coverage of appliances in New Zealand by the Australian labelling system is very patchy.

In June 1991 the Electricity Supply Association of New Zealand launched its voluntary WaterMark scheme. Under this scheme, manufacturers can be licensed to place a proprietary label on hot water cylinders. The label has three parts. It consists of the registered WaterMark symbol, a grade label and a recommendation label. The WaterMark grading system ranges from Grade A to Grade D (refer to Table 11.1). Grade A cylinders have the lowest heat loss and comply with NZS4602:1988 (low pressure cylinders), or NZS4606:1990 (mains pressure cylinders). There is provision to extend the grading system in future to Grade AA and Grade AAA if manufacturers sufficiently improve the performance of the most efficient cylinders.

The energy efficiency implications of the different grades have been discussed in Chapter 11. There is no information on the label that expressly reveals that there is a hierarchy of efficiency from Grade A down to Grade D. The label does not contrast the energy consumption of the various grades. It is assumed that by having an alphabetical grade on cylinders, purchasers will make themselves aware of the differences between grades.

The Environmental Choice New Zealand scheme is a certification programme aimed to identify environmentally preferable products. The Environmental Choice certification mark consist of a simple logo with the words "Environmental Choice New Zealand" and a prominent "tick". The mark is owned by the Ministry for the Environment, which contracted with Telarc New Zealand in 1991 to run the scheme.

Telarc is the national technical and quality system accreditation and certification authority. Telarc's original function was to accredit testing laboratories. In 1983, Telarc's empowering legislation was amended to add quality assurance certification; this meant independently assessing, auditing and certifying organisations' quality assurance systems. Any product made, used or disposed of in a manner that significantly reduces the harm it would otherwise cause the environment is a potential candidate for Environmental Choice certification. Presently (i.e. 1995), criteria for certification have only been developed for a few types of products (none are electrical appliances).

Future Directions

There are concerns over the efficacy of compulsory labelling of all appliances in a class (e.g. refrigerators), based on the schemes currently in use. These concerns relate to consumer recognition of significance of the label (does it deal with energy efficiency, product quality or value for money) and the inability of many consumers to use the label to differentiate products or otherwise interpret the information. Consumers are presented with the energy consumption according to a test (the label) and the up front cost (the price). Few could calculate the life-cycle cost, which is a good economic indicator and basis for comparison, but depends on power price, which can vary from place to place.

Another problem with stepped labelling systems like the Australian system is that, in some cases, manufacturers produce a few highly rated products, so that corporate responsibilities are discharged, but then market poor performing models. Alternatively, where competition on the basis of efficiency appears to be working, quite a number of appliances end up in the top category. There is no incentive for further improvement. An endorsement labelling scheme can address both manufacturer and consumer issues.

With endorsement schemes, not every appliance is labelled, only those that meet special requirements. The main requirement will usually be a high energy performance for the class of product. The product class can be based on size/application and, in some cases, cost category. A reputable independent agency sets the requirements and awards the endorsement labels. Endorsement label programmes do two things: they identify which models are energy efficient and they advise consumers, through advertisements and other information vehicles, to choose the labelled product if they care about energy issues or wish to save on life-cycle costs.

For a spectrum of products covering all ends of the market (cheap and so called quality goods), the consumer is told the best to buy from an efficiency perspective. If the consumer can only purchase at the economy end of the market, the most energy efficient option will still be noted.

Establishing mandatory minimum energy performance standards (MEPS) is another potentially cost effective way of improving appliance efficiency. Standards can work in conjunction with labelling schemes or on their own. A strong case can be made for using standards to affect parts of the market weakly affected by labelling approaches. In these circumstances, standards will usually be designed to eliminate very poorly performing appliances from the market.

Using standards to eliminate poor performing models will usually be economic for the householder. The high running costs of these models outweighs the lower upfront costs. The rare cases where these models might be operated at lower overall cost (e.g. infrequent use in holiday homes) is unlikely to erode the national benefit.

In countries that have had compulsory labelling schemes for some time, there is a trend towards setting MEPS. Policy analysts and politicians have either felt that compulsory labelling was not effective, or that further advances would be too slow. There is some experience in the United States that suggest using MEPS to set a baseline and using endorsement labelling schemes to reward the top performing appliances is a sound policy combination.

In New Zealand, the government is seriously considering establishing MEPS. Work on either making the Australian labelling scheme compulsory or developing an endorsement scheme (either through EECA and/ or power companies) is progressing slowly. Sections 14.6 and 14.7 set out the basic principles and techniques for MEPS setting.

14.6 Minimum Performance Standards

This section introduces general principles that have been developed overseas for setting and introducing MEPS.

The Nordic countries have taken strong interest in the MEPS and labelling issues. In November 1990, the Nordic Ministers of Energy appointed the NORDNORM Commission to deal with efficiency standards and labelling for electrical household appliances. The NORDNORM Commission has published a proposal setting out principles for MEPS Nordic Council of Ministers 1992. The Commission has also investigated the energy savings that could come about from implementing MEPS for refrigerators and freezers (Moller, 1992).

MEPS Principles

After reviewing experience with MEPS and investigating a wide range of issues evoked by this form of public policy, the NODNORM Commission recommended in its proposal document a number of guiding principles. The main ones relevant to New Zealand are:

- MEPS should be dynamic and graduated — MEPS should rise in steps at regular intervals, such as every three years, and be combined with other initiatives aimed at encouraging the production of appliances more efficient than the standard requires.

- Sufficient lead time should be provided — MEPS should be advised in advance so that the necessary product development can take place. Once the MEPS comes into force, a period of time, up to a year, should be allowed to clear old stock.
- Standards should be based on technical analysis — Technical analysis together with energy reduction targets and other socioeconomic goals should be used to derive MEPS rather than ad hoc decisions.
- Voluntary and compulsory MEPS should be considered — The first step in a number of staged MEPS should be based on negotiations and voluntary agreements with manufacturers. If this is successful, then subsequent steps can also be voluntary; otherwise compulsory MEPS are required.
- Initially MEPS should be applied to fridge/freezers — Once some experience is gained, MEPS can be set for other appliances, such as electric water heaters, ovens, washing machines, dryers and dishwashers.
- Appliance sales and performance should be disclosed — Manufacturers and importers should provide information to a responsible authority on the sales and energy consumption of the appliances they market.

The "other initiatives" referred to under the first principle listed above can include special endorsement labelling schemes that identify the top performing models at any time. In New Zealand, hot water cylinders may be a higher priority for MEPS than refrigerators and freezers. The key principles from the list above are that MEPS should be set on the basis of technical analysis and should be introduced in stages.

Staged Introduction

The most effective approach to MEPS is considered to a dynamic one whereby standards are raised progressively. The initial aim is to eliminate poor performers; the final aim is to pull the market, to speed up efficiency improvements, which perhaps the market will only realise at a slow rate. Figure 14.1 shows the three step approach adopted in the United States. The first efficiency standards for refrigerators and freezers (Step 1) was published in 1987 and came into force in 1990. In 1990, these standards were updated (Step 2) and are to apply from 1993. Another revision (Step 3) is planned to come into effect in 1998.

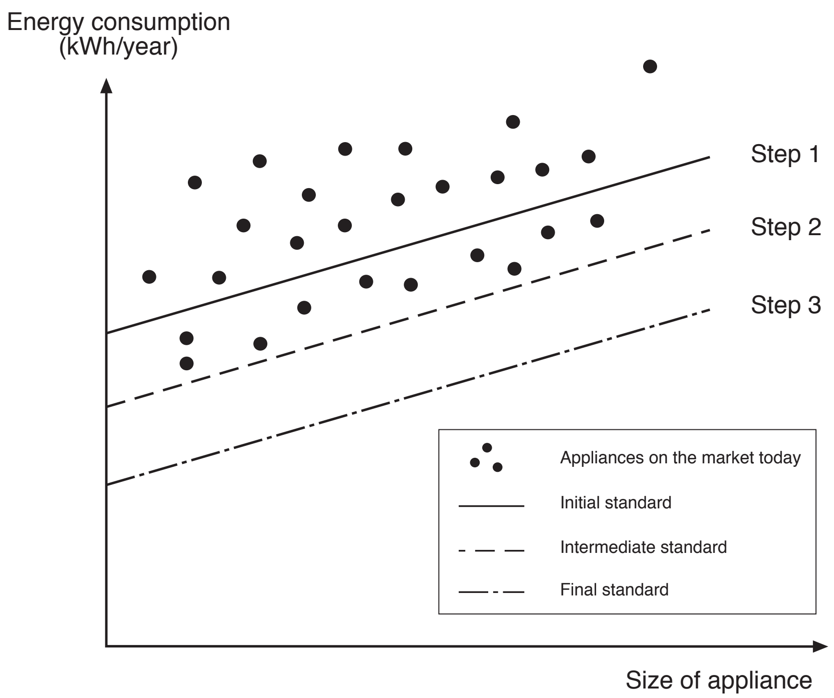


Figure 14.1: Graduated MEPS setting

The first step is usually designed to correspond to the current market average or the bottom end of the top third in terms of energy efficiency. The second step is set to the current economic optimum. The third step, which is telegraphed well in advance, aims to stimulate technical innovation and cost reduction so that the future economic optimum corresponds with even more efficient appliances. Both second and third steps can take into account future changes in electricity prices.

Not all countries have gone to declaring the third step. Figure 14.2 shows actual data and the results of technical analysis for refrigerators in Denmark. Note that one appliance model on the market already exceeds the second step in the MEPS.

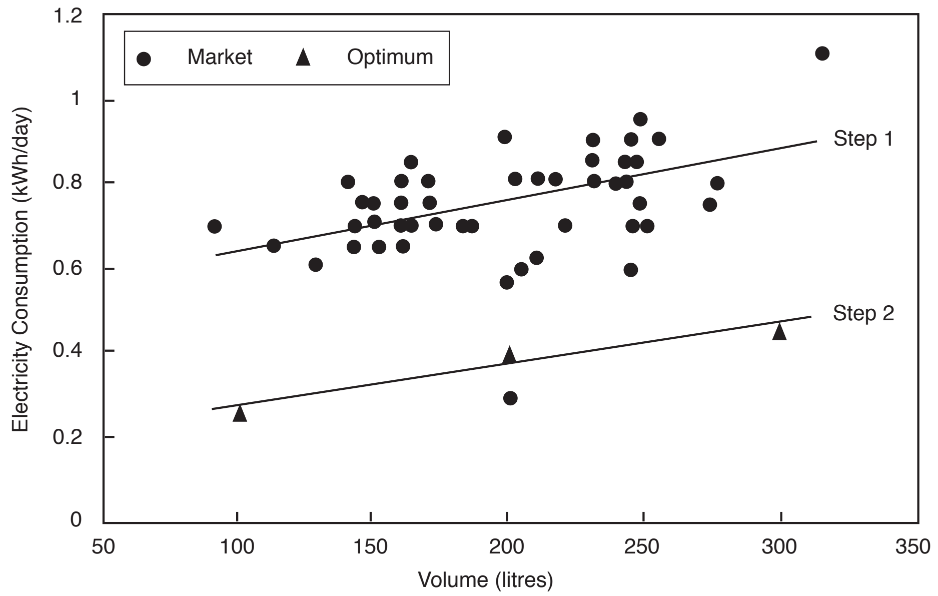


Figure 14.2: Danish example of graduated MEPS

Economic Analysis

Section 14.7 describes the technical method of setting MEPS. Essentially, a cost-benefit approach is adopted. Nearly all current appliances are sub-optimal in terms of energy use due to perceived or real consumer resistance to increased up-front costs. Raising standards is good for energy efficiency and national economic efficiency.

The US MEPS are set on the basis of a economic optimisation of technical potentials, working on average appliance use. Calculations of costs from the period 1990 to 2010 predict that with the MEPS, Americans will have to pay $31 billion ($31,000M) more for their appliances, in today's prices. They will, however, save $76 billion on their electricity bills (reported in the NORDNORM Commission proposal document). The sensitivity of the US predictions to key assumptions (e.g. power prices) has been tested and, for all the realistic possibilities, benefits are expected to outweigh costs. It is estimated that the public administrative costs associated with investigating and negotiating the MEPS amounted to $50 million between 1979 and 1991 (1/1000 of the net benefit). No estimate is available for private costs associated with establishing MEPS. It is quite likely that they would be of the order of tens of millions of dollars as well. Nonetheless, the American economy and consumers will be better off by billions of dollars due to MEPS.

The average efficiency of appliances in New Zealand is lower than in the US, but power prices are similar, so the scope for cost effective improvement may be greater in New Zealand. The MEPS establishment cost per appliance in New Zealand need not be any higher than in the US. The US system was implemented after many years of rancour between individual states, the government, environmental groups and manufacturers. Now that the case for MEPS has been established in the USA and other jurisdictions, effort in New Zealand should be focused on setting levels.

14.7 MEPS Technical/Economic Analyses

The starting point for setting MEPS is the present appliance market. For each class of appliance (e.g. 300-litre refrigerators), a number of base models are identified with energy consumption close to the market average for an appliance of the size in question. Manufacturers or engineers then supply information about the cost of a number of defined design options for making efficiency improvements, such as increased insulation.

A computer simulation model calculates the electricity saving for each design option and appliance. Present value life-cycle costs are then calculated for each design option. Figure 14.3 illustrates the results from a Danish study (Moller, 1992) for three discount rates (5%, 7% and 10%). It also shows that two design improvements (a and b) lead to the minimum life-cycle cost. The optimum point is not very sensitive to discount rates. It is often found that the number and type of technical options leading to the economically optimum point is not highly sensitive to electricity prices either. Curves similar to those in Figure 14.3 are found, but with the higher electricity price cost-curves at the top. Lower electricity prices tend to flatten the curves, while higher prices make the approach and departure from the optimum a bit steeper.

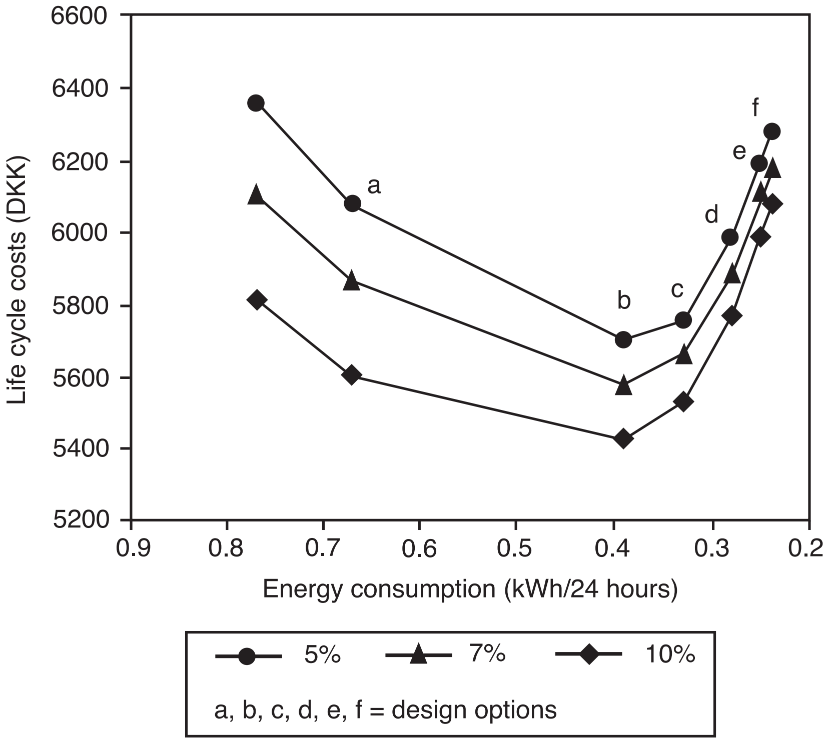


Figure 14.3: Lifecycle costs for different design options

Further improvements in efficiency are feasible beyond the optimum point, but the lifecycle cost (DKK — Danish Krone) rises steeply. In this example, however, energy use could be made to fall by two-thirds while still keeping lifecycle costs lower than they are at present. Adding one or two further technical options (c or d, depending on discount rate) beyond the economic optimum would raise capital costs but reduce electricity costs enough so that lifecycle costs would be less than at present.

MEPS Decision Making

The objective data in Figure 14.3 allows informed decisions to be taken about the levels of MEPS. Figure 14.4 shows a three-step MEPS proposal. The line connecting Steps 1 through to Step 3 shows the relative impact of progressively adopting tighter MEPS on the average appliance electricity consumption (left axis). The other line in Figure 6 shows the appliance lifecycle costs (right axis) for different technical options (these are listed in the key to Figure 14.4). The two lines can be connected by vertical lines to show the best technical option for each MEPS Step and also the payback period. The baseline, technical option 0, represents the average cost, technology and performance of existing appliances.

The proposal in Figure 14.4 is for the first MEPS step to be set at a payback period of two years. Step 1 is above the current appliance average performance and will require additional capital investment for many appliances. Step 2 corresponds to the minimum lifecycle cost. Step 3 was set at a lifecycle cost to consumers no greater than the current level (draw a vertical line through Step 3 and read the lifecycle costs where the line intersects the appliance technical option curve - around option +4).

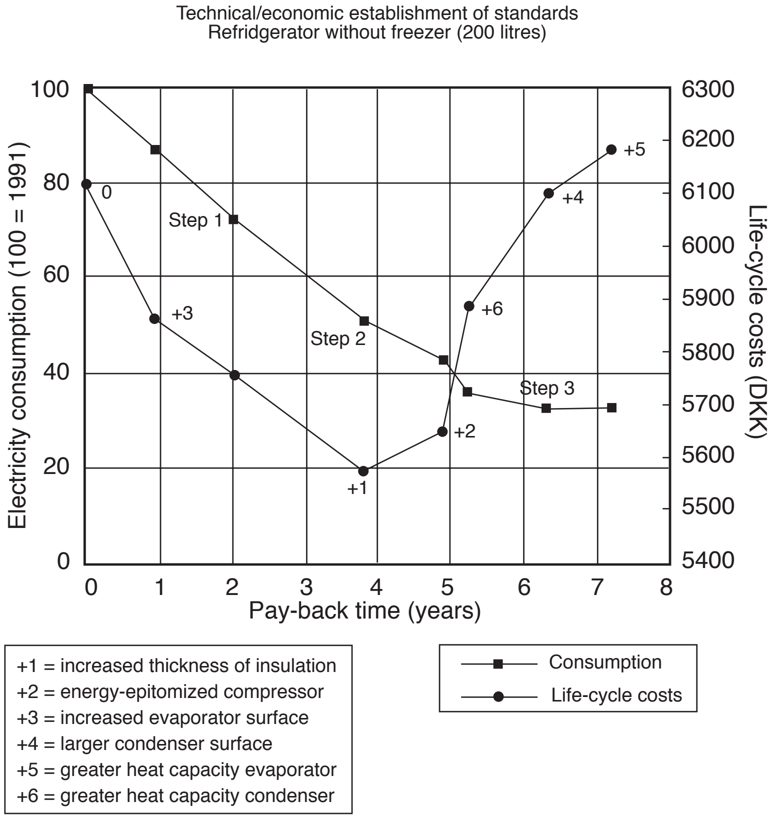


Figure 14.4: Technical-economic MEPS setting

Figure 14.4 shows that Step 1 will reduce electricity consumption of the average appliance by 25%. The standard can be achieved by increasing the evaporator area, the most economical change amongst the options investigated, and by partly increasing the thickness of the insulation. Step 2 means a 50% reduction in appliance energy use and can be achieved by increasing the thickness of the insulation from 30 to 60 mm. Step 2 represents the economically optimum point.

Step 3 could be foreshadowed as a future MEPS. For a variety of public policy reasons, it may be desirable to push ahead and achieve greater energy savings sooner rather than later. At Step 3 lifecycle costs are no greater than at present. Purchasers will have to pay more for an appliance, but the additional upfront cost is compensated by the reduced running costs.

Step 3 MEPS can be achieved at least cost by implementing all the improvements analysed, except increasing the heat capacity of the evaporator. Average energy use with Step 3 will be 67% less than present consumption. By the time Step 3 is implemented, technological innovation and production improvements may mean that it is now the economically optimum point — the shape of the curves in Figure 14.4 is not fixed and can change over time.

Embodied Energy Issue

An interesting issue is whether the extra energy required to produce and install more insulation, manufacture larger heat exchangers, etc. erodes the energy savings from more efficient appliances. This has been studied (Pedersen, 1992). The issue can be expressed in terms of energy recovery time — the time required for an appliance to save the extra energy expended in fitting energy efficiency features. At the economically optimum point for a range of Danish refrigerators, the energy recovery time was lower than 0.6 years, with an average below 0.5 years. If all the technical options analysed were implemented (+1 to +6 in Figure 14.4), then the average energy recovery time increases to only 0.8 years. For appliances with expected service lives of 15 years or more, the total energy benefits of efficiency features are clear.

Bibliography

Collins C (1993). *Energy Efficiency in New Zealand Homes — Appliance Labelling, Minimum Performance Standards, other Energy Efficiency Policies*, report to EECA, Wellington.

Colmar Brunton Research (1995). *Qualitative Report on Energy Efficiency in the Whiteware Market*, report prepared for EECA, Wellington.

Moller, J (1992). *Electricity Savings from Implementation of Standards for the Electricity Consumption of Refrigerators/freezers*, DEFU technical report 300 UK, Denmark.

Nordic Council of Ministers (1992). *NORDNORM Commission, Principles for Efficiency Standards for the Electricity Consumption of Household Appliances*, Joint Nordic Proposal (English translation, Margaret Malone).

Pedersen, P B (1992). *Engineering Analysis Concerning Efficiency Standards for Refrigerators and Freezers in Denmark — Preliminary Study Report to the Danish Energy Agency and Norwegian Water Resources and Energy Administration*.

United States Department of Energy (1991). *Energy and Global Warming Impacts of CFC Alternatives Technology* (known as the AFEAS Report).

United States Environmental Protection Agency (1993). *Multiple Pathways to Super-efficient Refrigerators*, EPA-430-R-93-008.

Wilkenfeld George and Associates (1991). *Residential Appliances in Australia: An Assessment of Market and Technology Developments, with Particular Reference to Energy Efficiency,* report prepared for the State Electricity Commission of Victoria Demand Management Unit.

Wilkenfeld George and Associates (1991). *Review of Residential Appliance Energy Labelling*, State Electricity Commission of Victoria.

Wilkenfeld George and Associates (1993). *Benefits and Costs of Implementing Minimum Energy Performance Standards for Household Electrical Appliances in Australia*, prepared for Demand Management Unit, State Electricity Commission of Victoria (3 volumes).

Chapter 15
Economics of Domestic Energy Efficiency

15.1 Introduction

This chapter examines a number of economic decision tools commonly used to assess energy efficiency investments. According to conventional wisdom, domestic energy efficiency is not very economical in New Zealand. Reasons for this attitude include:

- energy prices are too low;
- energy efficiency costs are high;
- the climate is mild enough that energy saving measures are not really justified; and
- people don't want their houses warm anyway, and thus don't need efficiency.

All these assumptions are questionable. A major concern is that people do not understand how to apply economics to household energy efficiency decisions. Furthermore, many people may be mislead by economic terms such as payback period. Most are not able to compare this performance indicator with normal investment criteria such as bank interest rates. The problem is compounded by the assumption or advice that householders are, or should be, looking for short payback periods, possible as low as two years.

This chapter examines the concept of payback period and shows how this measure can be translated into an internal rate of return, a parameter more amenable to comparison with interest rates. A number of examples are presented that show that seemingly poor energy efficiency investments (based on payback period) are actually better than bank investment or putting capital into other ventures. Life-cycle costing and other methods of economic analysis are then discussed.

15.2 Payback as a Barrier

One of the major assumptions of energy efficiency is that measures with a simple payback time of over two years would not be considered economical for most homeowners. The use of the term payback has negative connotations. While payback period is used for energy efficiency investment decisions, performance indicators better suited to making comparisons are used for most other investment decisions.

Payback is essentially the reciprocal of the rate of return on investment. Typically, in business an investment with a return rate of over 10% per year is considered worthwhile, and over 20% per year is excellent. These returns correspond with paybacks of ten years and five years, respectively.

When investors decide they need a two-year payback to justify an energy efficiency investment, they are implicitly saying they consider that the investment does not improve their capital asset, so that the expenditure must be recouped through the returns (energy savings), or the risk of non-performance is great, or that the product life is expected to be very short (or a combination of all three positions).

Investments in energy efficiency have some differences from normal investments in that they are not very liquid — it is difficult to remove insulation from one's ceiling and resell it to recoup some of the value. This is different from company shares or bank deposits, where procedures to regain the capital invested are well established. However, the other risks should be very small. The performance of energy efficiency technologies and product lifetimes are generally well established and should be covered by warranties.

In addition, because the returns on energy saving investments in the domestic sector do not show up as visible income, there is no tax liability on them. The returns on most conventional investments are taxable. For example, a person in the 33% tax bracket who would save $500 per year in energy costs from a $1500 investment might decide not to invest as this appears to be a three-year payback. However, to return $500 per year net from a conventional investment would require a 50% return on investment ($750 per year gross return), which would then be taxed down to $500 per year. In the commercial sector, this does not apply, because energy expenditures are tax-deductible as business expenses.

The return on an energy saving investment corresponds to the reciprocal of simple payback only for the case of constant energy prices and a very long lifetime for the energy saving technology. A more accurate performance indicator is the internal rate of return (IRR), which is the discount rate such that a stream of cashflows equals the initial investment. The simplest case is one when the investment has no salvage value at the end of its life and causes no additional expenses, such as maintenance. In that case, the cashflows are the saved energy costs. The IRR can be compared directly to the rate of return on an investment where the initial investment is returned at the end of the period and interest, less tax, is paid (as would be the case with a bank term deposit).

The following two tables (Table 15.1 and 15.2) show the internal rates of return for simple paybacks (SPB) varying from two to ten years, with investment lifetimes from two to 16 years, at 6% per year energy price inflation (probably the likely upper level), and also at zero energy price inflation for comparison (though this is unlikely given the resource constraints that New Zealand is beginning to experience in energy supply).

Table 15.1 shows, for example, that the IRR of an investment with a five-year simple payback and a ten-year life would be equivalent to a 22% per year return rate from a bank, if the energy savings were taxed at the same rate as the interest on the bank deposit. This table represents, arguably the most favourable situation for energy efficiency from a business perspective. If energy savings were not taxed (household situation), the IRRs would be higher.

SPB =	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	8 yr	9 yr	10 yr
Lifetime									
2 yr	6%	-	-	-	-	-	-	-	-
3 yr	31%	6%	-	-	-	-	-	-	-
4 yr	43%	19%	6%	-	-	-	-	-	-
5 yr	50%	27%	14%	6%	-	-	-	-	-
6 yr	53%	32%	20%	12%	6%	-	-	-	-
7 yr	55%	34%	23%	16%	10%	6%	-	-	-
8 yr	56%	36%	26%	18%	13%	9%	6%	-	-
9 yr	57%	38%	28%	20%	16%	12%	9%	6%	-
10 yr	58%	39%	29%	22%	17%	14%	11%	8%	6%
12 yr	58%	40%	30%	24%	19%	16%	13%	11%	9%
14 yr	58%	41%	31%	25%	21%	18%	15%	13%	11%
16 yr	58%	41%	32%	26%	22%	19%	16%	14%	13%

Table 15.1: Internal rates of return (annual), with 6% per year energy price inflation

Table 15.2 represents the least advantageous set of circumstances for energy efficiency from a business perspective. With no price inflation, an investment with a five-year simple payback and ten-year life would be equivalent to a 15% per year interest rate from a bank deposit.

15.3 Investment Examples

This section examines four examples that, based on their payback periods, may not appear at first glance to be attractive investment opportunities. Closer examination using IRR shows them to be very attractive.

Example 1: This looks at the cashflows over ten years for investing $10,000 in an energy saving technology with a five-year simple payback and a life of ten years or more, compared to bank deposits returning 7% per year. For simplicity, all energy savings are assumed to occur in discrete amounts at the end of each year, as does the interest on the bank investment. In this example, no tax is charged on the interest on the investment, the energy savings are not invested and the price of energy is held constant.

As can be seen from the cashflows in Table 15.3, over ten years with no investment of the energy savings, no increase in energy cost and no tax effects, energy efficiency still returns more money than a conventional investment.

SPB =	2 yr	3 yr	4 yr	5 yr	6 yr	7 yr	8 yr	9 yr	10 yr
Lifetime									
2 yr	-	-	-	-	-	-	-	-	-
3 yr	23%	-	-	-	-	-	-	-	-
4 yr	35%	13%	-	-	-	-	-	-	-
5 yr	41%	20%	8%	-	-	-	-	-	-
6 yr	45%	24%	13%	5%	-	-	-	-	-
7 yr	47%	27%	16%	9%	4%	-	-	-	-
8 yr	48%	29%	19%	12%	7%	3%	-	-	-
9 yr	48%	30%	20%	14%	9%	5%	2%	-	-
10 yr	49%	31%	21%	15%	11%	7%	4%	2%	-
12 yr	50%	32%	23%	17%	13%	9%	7%	5%	3%
14 yr	50%	33%	24%	18%	14%	11%	9%	7%	5%
16 yr	50%	33%	24%	19%	15%	12%	11%	8%	6%

Table 15.2: Internal rates of return (annual), with no energy price inflation

Year	Energy efficiency investment		Bank investment	
	This year's energy savings	End of year total savings	This year's interest	End of year bank balance
		$0		$10,000
1	$2,000	$2,000	$700	$10,700
2	$2,000	$4,000	$749	$11,449
3	$2,000	$6,000	$801	$12,250
4	$2,000	$8,000	$858	$13,108
5	$2,000	$10,000	$918	$14,026
6	$2,000	$12,000	$982	$15,007
7	$2,000	$14,000	$1,051	$16,058
8	$2,000	$16,000	$1,124	$17,182
9	$2,000	$18,000	$1,203	$18,385
10	$2,000	$20,000	$1,287	$19,672

Table 15.3: Cashflows for Example 1

Example 2: The same scenario is repeated with the same assumptions, except that the energy savings are invested in the bank at the same interest rate (7% per year), tax is charged on the interest earned at 33% and the price of energy rises at 6% per year.

Table 15.4 shows the cashflows. For simplicity, tax is levied at the end of the ten year period. The final row in the table shows the final position. In this case, the overall return from the energy saving investment ($32,324 - $10,000 = $22,324) is almost four times as high as the conventional investment ($16,480 - $10,000 = $6,480).

Example 3: A domestic consumer finances an energy efficiency investment with a five-year simple payback on their credit card, at 18% interest. Again, all the energy savings and all the interest are assumed to compound annually, and energy prices rise at 6% per year. The results are shown in Table 15.5. There is no tax to consider in this case as savings are used to pay off debt (note the caveat at the end of the next paragraph).

Year	Energy efficiency investment			Bank investment	
	This year's energy savings	This year's interest	End of year total savings	This year's interest	End of year Bank balance
			$0		$10,000
1	$2,000	$0	$2,000	$700	$10,700
2	$2,120	$140	$4,260	$749	$11,449
3	$2,247	$298	$6,805	$801	$12,250
4	$2,382	$476	$9,664	$858	$13,108
5	$2,525	$676	$12,865	$918	$14,026
6	$2,676	$901	$16,442	$982	$15,007
7	$2,837	$1,151	$20,430	$1,051	$16,058
8	$3,007	$1,430	$24,868	$1,124	$17,182
9	$3,188	$1,741	$29,796	$1,203	$18,385
10	$3,379	$2,086	$35,261	$1,287	$19,672
final position:	$26,362 (non-taxable)	$8,899 (taxable)	$32,324 (net after tax)	$9,672 (taxable)	$16,480 (net after tax)

Table 15.4: Cashflows for Example 2

Year	This year's energy savings	This year's interest	End of year balance owed
			$10,000.00
1	$2,000.00	$1,800.00	$9,800.00
2	$2,120.00	$1,764.00	$9,444.00
3	$2,247.20	$1,699.92	$8,896.72
4	$2,382.03	$1,601.41	$8,116.10
5	$2,524.95	$1,460.90	$7,052.04
6	$2,676.45	$1,269.37	$5,644.96
7	$2,837.04	$1,016.09	$3,824.01
8	$3,007.26	$688.32	$1,505.07
9	$3,187.70	$270.91	–$1,411.71
10	$3,378.96	–$254.11	–$5,044.78

Table 15.5: Cashflows for Example 3

In the first year, the $2000 energy savings are mostly offset by the $1800 interest payment, so the debt drops by only $200. At this rate, it would take 50 years to break even and pay off the debt through energy savings. However, in succeeding years, the interest payments drop as the principal owed is reduced, and the energy savings continue to increase so that, after about eight and a half years, the loan is repaid and net benefits accrue. If these net benefits are invested, then tax will be liable on the return.

This eventual benefit could be predicted from the 22% IRR shown in Table 15.1 (at five-year simple payback, ten-year lifetime), which is greater than the 18% credit card interest rate.

If the investment had a life of less than eight to 10 years, then it may not have been an attractive proposition using credit cards as the source of finance, given their high interest rates. If the investment was something long lived, such as insulation, and adds to the value of the home, then even at the high interest rates of credit cards, and with even little in the way of energy price rises, it could be a worthwhile proposition.

Example 4: A domestic customer considers a $10,000 energy saving investment with a four-year simple payback but only a five-year life, where the savings would be invested in a bank account paying 13% per year interest, compared to investing the whole amount in the bank account from the start, at a time when energy prices are rising at 6% per year.

A four-year simple payback with only a five-year life sounds like a poor investment, but from Table 15.1 this is seen to have a 14% IRR, better than the 13% on offer from the bank here.

Year	Energy efficiency investment			Bank investment	
	This year's Energy savings	This year's interest	End of year Bank balance	This year's interest	End of year Bank balance
			$0		$10,000
1	$2,500	$0	$2,500	$1,300	$11,300
2	$2,650	$325	$5,475	$1,469	$12,769
3	$2,809	$712	$8,996	$1,660	$14,429
4	$2,978	$1,169	$13,143	$1,876	$16,305
5	$3,156	$1,709	$18,007	$2,120	$18,424
sum:	$14,093 (non-taxable)	$3,915 (taxable)	$16,702 (net after tax)	$8,424 (taxable)	$15,644 (net after tax)

Table 15.6: Cashflows for Example 4

As expected from the IRR (but not the payback period and life), even in this case the energy efficiency investment yields a higher return than the conventional investment.

15.4 Lifecycle Costing and other Issues

The examples in the last section considered the net position of a householder at the end of a set period. Another way to look at investments is to calculate life-cycle costs and benefits, bring them to a net present value (NPV), and then redistribute them as annual amounts. The annual net amount for different investment opportunities can be compared.

When the total expenditures for energy and capital are compared on the same grounds by looking at the annual expenditures for each (as represented by the extra mortgage payments needed to cover the costs of energy efficient features), energy efficiency can be seen in a different light. For example, by calculating the annual expenditures needed to cover the costs of extra insulation, the payback "hurdle" disappears. Usually, the extra annual payments needed to cover the cost of such measures are less than the energy savings they create. In such a case, the buyer is always "money ahead" on an annual cashflow basis.

Case Study

This technique can be applied to calculate the optimal levels of insulation or other energy efficiency techniques by figuring the annual costs of energy and mortgage repayments and seeking the lowest sum of the two. This point yields the lowest overall cost.

For example, if loosefill macerated paper costs $5.50/m^2 to give an insulation level of R-3.2, and installation costs an additional $1/m^2, its total cost is $6.50/m^2. To get the linearised insulation cost, this is divided by the increased R-value. In this case, the linearised cost is $2.00/m^2 per R-value. This relationship between R-value and cost can then be related to mortgage rates to produce an annual cost of installing different levels of insulation (i.e. R-value) in a home.

Figure 15.1 shows the annual costs of both heat and mortgage payments plotted versus insulation level (in R-values, where each R-value is approximately equal to 50 mm of fibreglass or loosefill insulation).

For a given R-value the annual heating bill can be calculated per square metre. The heat lost per square metre of ceiling, assuming 2000˚C days of heating (characteristic of Wellington buildings heated to an average temperature of 18˚C) and heat energy costs of 10¢/kWh is shown as the dashed line. The annual costs of the insulation, assuming a 25 year, 8% per year mortgage, are shown as the dashed/dotted line. The sum of these two costs is shown as the solid line.

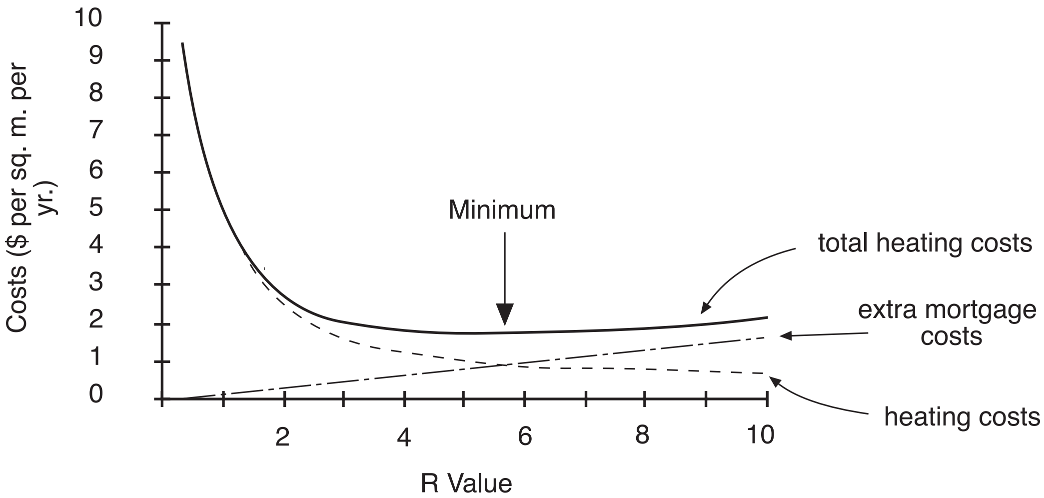


Figure 15.1: Annual costs of heat and mortgage payments vs insulation level

As can be seen, the cost of heat declines continuously as the insulation level increases, but soon reaches a "diminishing returns" exponential decline. The costs of the insulation, however, rise linearly. The lowest total cost is at R-5.5, a much higher level than normally considered cost-effective (the standard insulation level is under R-3 for New Zealand ceilings). The total cost curve is fairly flat between R-4 and R-8.

Lifecycle costing expressed as annual amounts can be readily used to assess benefits and to compare investments. The net heating cost of investing to R-2.4, which might be the minimum requirement, is around $2.50 per metre, while at R-5.5 the cost is closer to $1.50 per metre or a savings of $1 per metre. For a 100 square metre home, this means an improvement in the household budget of around $100 per year. The really big gains, of course, are obtained in going from low insulation levels (R0.5-1.0) to reasonable levels (R2.0-3.0).

Other Issues

In some overseas markets, the value of energy savings in a house is used to adjust the "qualifying ratio" for prospective mortgages (this is the ratio of mortgage payments to total net income of the mortgagee). The logic behind this is that a more energy efficient house will require lower energy purchases to maintain the same comfort level as a less energy efficient house, so the owner will have more cash available to pay their mortgage.

This is done by adding the mortgage payments to the energy costs for the prospective homeowner and using that sum in the qualifying ratio. Then, with lower energy use, a higher-priced house can still be purchased by a person on a given income.

Given that many customers are unwilling to invest in energy efficiency if its simple payback is more than two years, there is room for third-party investors to profit from this hesitancy. Overseas, Energy Service Companies (or ESCOs) have captured significant market share by investing in efficiency at others' premises and sharing the savings achieved with them. In New Zealand, ESCOs have not yet emerged in any significant numbers, but power companies could profit from this opportunity.

Power companies traditionally invest with the expectation of 10 to 20 year paybacks (for electricity generation stations) and have excellent access to capital. They also have existing contractual and billing relationships with their customers, and so are uniquely positioned to finance energy efficiency and share the profits and other benefits with their customers. The effects on both power company profits and customer costs is discussed in an article in *Current* magazine (Bishop, 1994).

15.5 Conclusions

Energy efficiency investments are not usually considered in the same rational light as other economic investments. An obsession with payback periods of less than two years indicates a perception of high risk or rampant confusion about the value of energy savings compared to other investments. Two-year payback investments correspond to return rates of over 50% per year, which are considered ridiculously favourable for other investments.

The use of the internal rate of return (IRR) to calculate the actual value of energy saving investments is recommended. Lifecycle analysis that yields comparable annual costs and benefits for different levels of energy efficiency is also helpful. This technique can be used to find the optimal level of efficiency investment.

In the future, energy efficiency may be used as a factor to extend the “qualifying ratio” used by lenders to decide whether potential borrowers can afford to service home mortgage debts. More energy efficient houses have lower operating costs, so presumably their owners will be more financially secure with lower risks, so their qualifying ratios should be increased.

In addition, as power companies and other third party investors develop mechanisms to share the value of energy savings with their customers, the full value of potentially cost-effective energy savings available in New Zealand (possibly in the order of $1 billion per year in 1994) will be realised.

Attachment: Economic Discounting Formulae

The following formulae can be used to determine the time value of money and compare present, future, and annual expenditures and returns (Marshall, 1980).

Single Compound Amount Formula (SCA)	To find F when P is known	$F = P\left(1+i\right)^N$
Single Present Worth Formula (SPW)	To find P when F is know	$P = F\dfrac{1}{(1+i)^N}$
Uniform Sinking Fund Formula (USF)	To find A when F is known	$A = F\dfrac{i}{(1+i)^N - 1}$
Uniform Capital Recovery Formula (UCR)	To find F when A is known	$F = A\dfrac{(1+i)^N - 1}{i}$
Uniform Present Worth Formula (UPW)	To find P when A is known	$P = A\dfrac{(1+i)^N - 1}{i(1+i)^N}$
Uniform Present Worth Formula Modified (UPW*)	To find P when A is escalating at rate e	$P = A\dfrac{(1+e)}{(i-e)}\left[1-\left(\dfrac{1+e}{1+i}\right)^N\right]$

Where:

P = a present sum of money

F = a future sum of money, equivalent to P at the end of N periods of time at an interest or discount rate of i

i = an interest or discount rate

N = number of interest or discounting periods

A = an end-of-payment (or receipt) in a uniform series of payments (or receipts) over N periods at i interest or discount rate

e = rate of escalation of A in each of N periods

References

Bishop, R (1994). "Profiting from energy efficiency", *Current* magazine, ESANZ, Wellington, February and April 1994.

Marshall, H E and R T Ruegg (1980). *Simplified Energy Design Economics - Principles of Economics Applied to Energy Conservation and Solar Energy Investments in Buildings*, Center for Building Technology, US National Bureau of Standards.

Chapter 16
Putting it Together — Southpower's Smarter Energy Show Home

16.1 Introduction

Southpower show homes are intended to bring to the attention of the public the best ideas and innovations in energy efficient house design and construction. Southpower's aim is to inform and enlighten people who are making decisions regarding capital investment when building new homes or renovating existing homes.

Each Southpower show home provides a case study of how energy efficient features can be incorporated into different scenarios. The first case study was a new four bedroom brick veneer home in the Christchurch suburb of Westmorland. The second case study involved taking an older weatherboard home and fully renovating it. The house was subsequently sold and relocated to Darfield for the new owner.

The third show home is a large house built in the American Colonial style, with a columned front entry and with all living spaces contained on the ground floor. A plan of the house is shown in Figure 16.1 and the building's details are given in Table 16.1. The living areas include an open front porch, a wide entry foyer, formal lounge (sitting room) and living room, which opens to the dining and kitchen areas. Also located downstairs is a laundry, a bathroom with shower and toilet, a study/bedroom and internal access to a double garage with loft space.

The upper floor comprises four bedrooms, including the large master bedroom with a walk-in wardrobe and an ensuite with spa bath. There is also a main bathroom with bath, shower and toilet that serves the remaining three bedrooms.

16.2 Background

Southpower purchased the house for its Show Home III project as a lockup shell and, after planning, had a total of seven weeks to complete construction. This meant fostering relationships with trades that could provide high quality work within a minimum time frame. There was no margin for error. Southpower takes its endorsement of products and services extremely seriously and, therefore, tests and reviews business relationships with suppliers. The various show homes have proved excellent mediums for this.

Southpower's show homes are also used as a venue to host evening sessions on specific topics. These may include:

- gas supply and appliances;
- construction (including exterior construction, linings, double glazing and insulation); and
- interior features such as bathroom ware (water saving taps and shower heads), energy efficient lighting, carpet and underlays, paint, appliances, underfloor and ceiling heating and methods of home heating.

Secondary schools, polytechnics, universities and various other groups are invited to the home for specific tours. Southpower also utilises the show homes for promotional campaigns. As part of the Show Home III project, Southpower, in conjunction with ECNZ, launched the HERO (Home Energy Rating Option) programme. This gives each home an energy rating on a scale of 1 to 10, with 1 being the lowest and 10 the highest. Show Home III has a maximum HERO rating of 10.

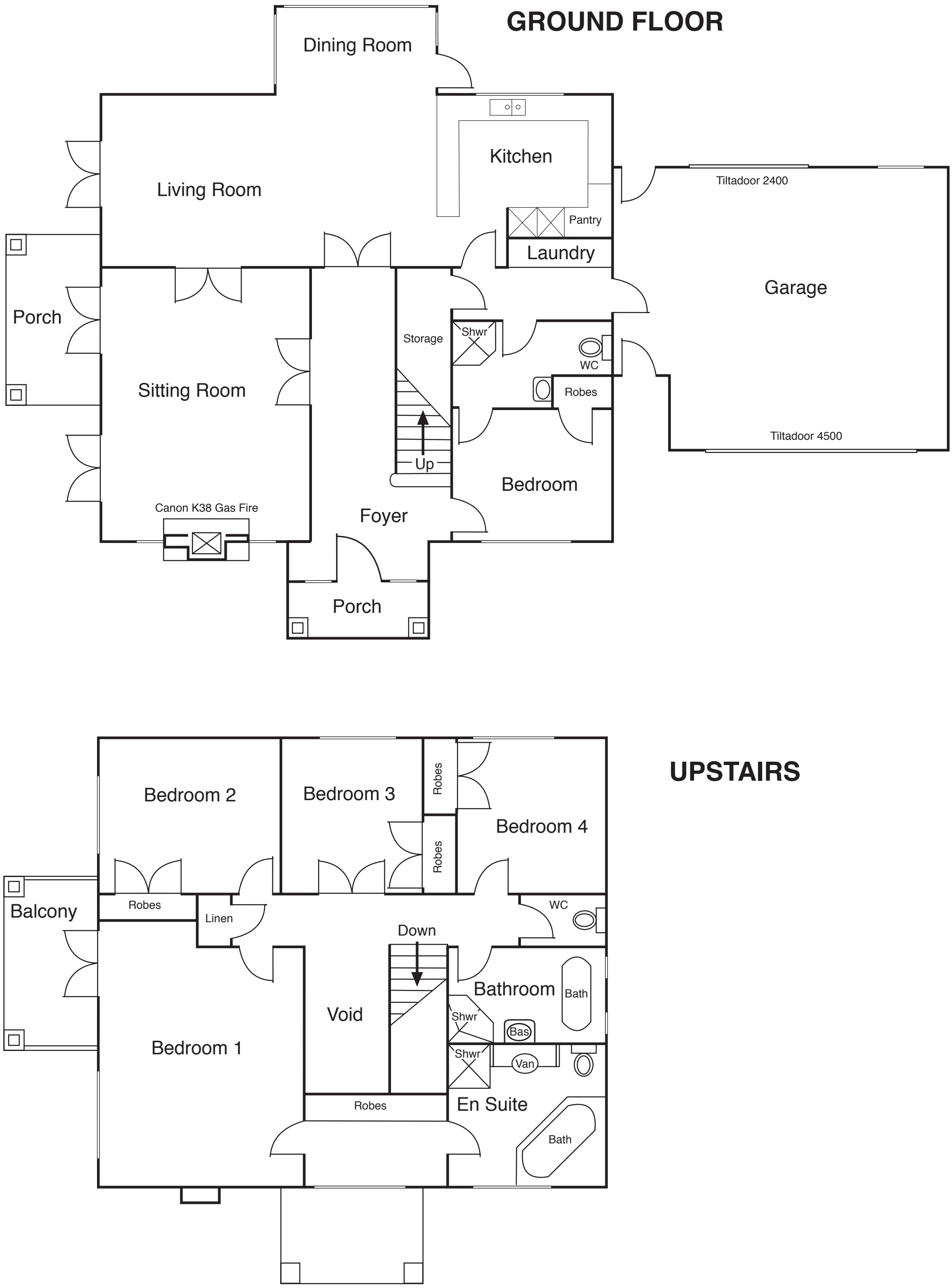


Figure 16.1: Floor plan of the Southpower Show Home III

Southpower established the following objectives for the current show home:

- to develop a show home that is decidedly different from previous show homes in order to stimulate a large number of visitors;
- to develop a show home with the latest in "smarter" energy technologies and design features;
- to provide an opportunity to work with new companies and evaluate performance standards;

- to utilise the home as a medium to discuss the products and services that Southpower is confident to endorse to the public; and
- to use the home to demonstrate the use of gas as a means of "smarter lifestyle" energy.

Floor area — ground	124 m^2	
Floor area — upstairs	114 m^2	
Garage	40 m^2	(430 sq. ft.)
Total floor area (excluding garage)	**238 m^2**	(2600 sq. ft.)
Ceiling area (upstairs)	124 m^2	
Exterior wall area (less windows)	177 m^2	
Window/glass area	65 m^2	

Table 16.1: Building details of the Southpower Show Home III

16.3 Home Features

As mentioned above, the Southpower Show Home III has achieved a HERO rating of 10 out of 10. Contributions toward this rating include:

- external wall insulation to a level of R3.4 (25 mm reinforced external plaster, with 40 mm of polystyrene on a totally dried timber frame and 100 mm fibreglass batts);
- ceiling insulation to a level of R3.4 (150 mm of fibreglass batts);
- floors covered with extra heavy duty underlay and wool carpet;
- double glazing utilised on all exterior windows and doors, with the exception of two small leadlight windows in the formal lounge;
- acoustic batts are utilised in the ceilings between the ground floor and upstairs and in internal walls between the bedrooms and bathrooms;
- the formal lounge and dining/kitchen areas of the home are lined with Fyreline Gib board as an added safety feature;
- energy efficient lighting is utilised throughout the entire home; and
- an 18 kW high efficiency LPG gas central heating unit, with insulated ducting to all rooms, heats the home to a selected temperature.

The central heating system operates to achieve overall comfort with a minimum of energy consumption by, firstly, being well matched to the needs of the entire house, and, secondly, through the use of thermostatic controls to ensure it only uses the energy needed to maintain the pre-selected temperature.

Air is drawn through the house via a centrally located return air duct and passes through the heater before being returned to the house by a network of smaller ducts. It is reintroduced through ceiling outlets at the outer edges of the house. From there, it slowly makes its way back to the return air duct to start the whole cycle over again. There is no build up of stuffy, stale air and no sudden temperature changes from room to room (natural gas central heating is covered in Chapter 10).

The system also allows for ducts to be individually controlled, thereby allowing the control of heat in certain rooms. Utilised correctly, this can assist in gas savings of up to 30%.

Additional points to note about the show home include:

- A heat recovery ventilation system allows stale air to be extracted from the home and the incoming fresh air to be warmed before it is mixed with the return air from the gas central heating system. This ensures a healthier living environment, as well as more efficient space heating.

- Ventilation in the bathrooms and laundry area is controlled by a humidistat air sensor, which means that fans are only utilised when triggered, thereby conserving energy.
- Ventilation in the toilet area is controlled by an occupancy sensor. The fans are only activated when someone enters the room.
- Gas cooking has been introduced into the home. Taking into account the current price differences between gas and electricity, it is more economical to cook with gas. The gas hob also allows instant high heat and a low heat cooking flame.
- The central ducting system also allows for cooling in the summer with a heat pump running at 240% to 300% efficiency.
- A 4.24 kW, 75% efficient flame effect LPG fire is located in the formal sitting room. Although this is not needed to heat the home, it can be utilised to provide a cosy atmosphere when required.
- An eight panel solar hot water system is utilised to heat a 360-litre water cylinder. It is expected that this system will heat all of the water needed during the summer and up to 75% of the water in winter. Electricity is used to boost the water temperature only when required. A digital solar readout device is situated in the kitchen so that its performance can be monitored.
- ESWA™ low temperature radiative underfloor heating is utilised in the kitchen and bathroom areas. This system is controlled by a 24-hour reprogrammable digital timer that combines thermostat and time controls.
- ESWA™ heating is utilised behind the bathroom mirrors to prevent steaming.
- Water saving shower roses for all showers.
- Ceramic half-turn tapware is used throughout the house to ensure water saving by reducing wear and leaking taps.
- Appliances with the highest energy efficiency ratings are used throughout the home, including dish-washer, fridge/freezer, washing machine and dryer.
- A central reprogrammable and fully adjustable temperature controller controls the heating, air condition-ing and air exchangers sharing one ducted system.
- Wiring in the home was based on exceeding the Medallion 2000 standard.
- The security system is infrared remote activated and has a panic switch located upstairs and two keypads covering the home's two main entrances. The main alarm panel is located under the stair space. The alarm is monitored by a security firm.
- Smoke detectors are permanently wired into the home.
- The television aerial outlets are based on a circulatory system that allows the best signal no matter where the televisions are placed.
- All external lighting is infrared controlled. Exterior lights can also be switched on manually.

16.4 Additional Costs of Energy Efficiency Modifications

Ceiling and Wall Insulation

The insulation levels are high compared to the New Zealand Building Code requirements. The additional cost for the external building envelope was $245 for the external walls and $450 for the ceiling.

Internal Floor/Ceiling/Wall Insulation

Internal 'sound' insulation is optional, however, insulation of some sort is recommended between the floors to reduce heating losses. To date, insulation between floors is not a requirement of the NZBC. The additional cost to place insulation between floors in the show home was $724.

Double Glazing

Double glazing offers sound and heat insulation. It also reduces the likelihood of condensation forming on the warmer internal glass surfaces. The double glazing units in the show home were produced by GlassTech and cover an area of approximately 65 m^2. The additional cost for the double glazing in the house (excluding any extra framing costs) was $4000. The slightly higher per square metre price (compared to a standard window installation) was due to the four sets of double doors.

Solar Water Heating

The Thermocell system used in the show home is of very high quality and makes excellent use of solar heating potential. The house uses a 360-litre hot water cylinder heated on night rate electricity and boosted with solar energy. The system can virtually stand alone during the hot summer months on solar power only. The system consists of:

- eight solar panels with an area of 5.6 m^2;
- a patented solar panel design;
- control system;
- pump;
- visual display unit; and
- "Sunstore" medium pressure hot water cylinder.

The additional cost for the show home, over a conventional system, was $3500 to $4000. However, this house has an unusually large system with some additional state-of-the-art features. An average home unit would cost an additional $2500 to $3300.

Overall Additional Cost

The overall additional costs over less efficient conventional systems/units was:

- Insulation — $1419
- Double glazing — $4000
- Solar water heating — $4000
- Total — $9419

Payback Times

Simple payback calculations based on the current price for energy show a three to five year payback for the insulation and double glazing and a seven to nine year payback on the solar heating. It should be noted that investments with payback periods as long as nine years can be attractive propositions. These investments show internal rates of return for long lived items (15 years or more), like solar heating, of between 8% and 14% depending on the rate of future electricity price rises. Few investments will provide such returns net of tax (see Chapter 15 for more details).

However, and possibly more importantly, the monthly savings on the power bill are significant, with 35% savings on heating and 50% to 60% savings on hot water. This gives an immediate reduction in running costs and, thereby, gives the customer more energy per dollar.

Chapter 17
Overcoming the Barriers to Energy Efficient Homes

17.1 Introduction

New Zealanders could improve the energy efficiency of their homes in ways that are economic and would improve their quality of life. The opportunities available are not being fully exploited. Why is this? It is difficult to list a clear-cut set of barriers to greater energy efficiency in homes. A factor that might be a barrier for one person or in one circumstance could provide a positive incentive for efficiency in another. Our collective attitudes to household energy efficiency, for example, contain a mix of strengths and weaknesses. The design of steps to increase the uptake of energy efficiency will need to bear in mind the complex interplay of forces that shape behaviour. Some insight into designing these steps can be gained by examining the following issues:

- public attitudes to household energy efficiency;
- priorities for home features and function;
- variation in household resources and incentives;
- structure of the New Zealand housing industry;
- government leadership and public policy response; and
- behaviour changes that have taken place over the last decade.

17.2 Attitudes to Energy Efficiency

In 1993, EECA commissioned the MRL Research Group to survey attitudes and behaviour concerning energy efficiency (MRL, 1993). The survey noted that some people distinguished between energy efficiency and energy conservation, while others did not:

- energy conservation — cutting back and using less energy, and (at a societal level) careful planning of energy usage;
- energy efficiency — making the best use of energy available in order to achieve the same result by using less energy or getting a better result for the same amount of energy.

The difference can be subtle but important and affects people's attitudes to energy efficiency. A significant portion of the community, perhaps up to a third, associate energy efficiency with austerity measures and therefore in conflict with their objectives for a comfortable house (see the next section). Nonetheless, overall, attitudes towards energy efficiency are generally positive.

Figure 17.1 provides a sample of some of the attitudes to energy efficiency. Working from the bottom bar up, it is clear that many New Zealanders recognise the connection between energy efficiency and reduced environmental impacts of energy use. People would be more energy efficient if they could be persuaded that it was beneficial to the country as a whole. They are receptive to energy efficiency marketing. It is clear that people want help on how to be energy efficient. The help could include better information, access to resources or persuading friends and family who are blocking change. Finally, many people believe the Government should do more to encourage energy efficiency.

When people were questioned on what they would like the government to do, the strongest response was to set an example in its own activities. This suggests a perceived lack of leadership in this area. This matter is taken up in a Section 17.6. Figure 17.2 shows other potential government actions that elicited a strong response. It is noteworthy that the public strongly support minimum energy standards (MEPS) for appliances, yet progress in this area is slow (refer to Chapter 14 for information on MEPS). There are minimum insulation standards for new residential buildings, but older homes present a problem, especially those in the rental market.

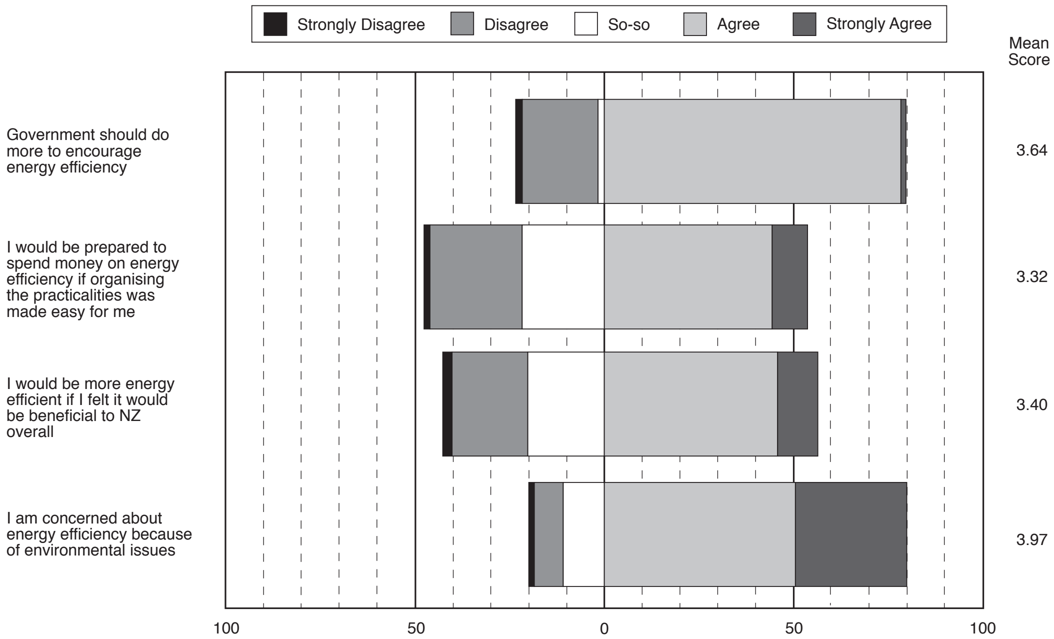


Figure 17.1: Energy efficiency attitudes of the general public (MRL, 1993)

It is clear that people see a connection between energy efficiency and economics. The call for incentives such as loans and subsidies will, in part, reflect the problems the lower-waged sector of society has in finding spare capital for efficiency investments. It is quite likely that it also reflects misunderstandings about the favourable economic return that some efficiency investments can provide (see Chapter 15). Somewhat disconcerting, more than a quarter of people interviewed said that nothing would encourage them to be energy efficient (MEPS would force their hand, of course).

Around 40% of people consider their home less than “quite energy efficient”. When presented with a list of potential energy efficiency investments or behavioural changes, most people could recall having undertaken one item. However, nearly two-thirds of people had not started any new actions in the last year. Individual interpretations of the barriers to action include:

- the initial capital cost is too great/or the investment is not worthwhile;
- they think they are too busy and/or regard making changes as inconvenient;
- they think their home/lifestyle would be less comfortable as a result;
- they are efficient and nothing more can be practically done; and
- other household members frustrate their efforts to be more efficient.

This information indicates that firstly, the culture of energy efficiency needs to be more widespread, based on a broad appreciation that it is beneficial. Any connection between energy efficiency and austerity needs to be dispelled. Secondly, the household economic aspects of energy efficiency need to be better explained. For some sectors of the community, resource assistance may be desirable. Energy efficiency needs to be packaged so that accessing information and acting on it is neither bothersome nor inconvenient. For example, plumbers could routinely offer to fit low-head shower heads or wrap cylinder when they visit a house on a maintenance call. This would add value to their business and be convenient for householders.

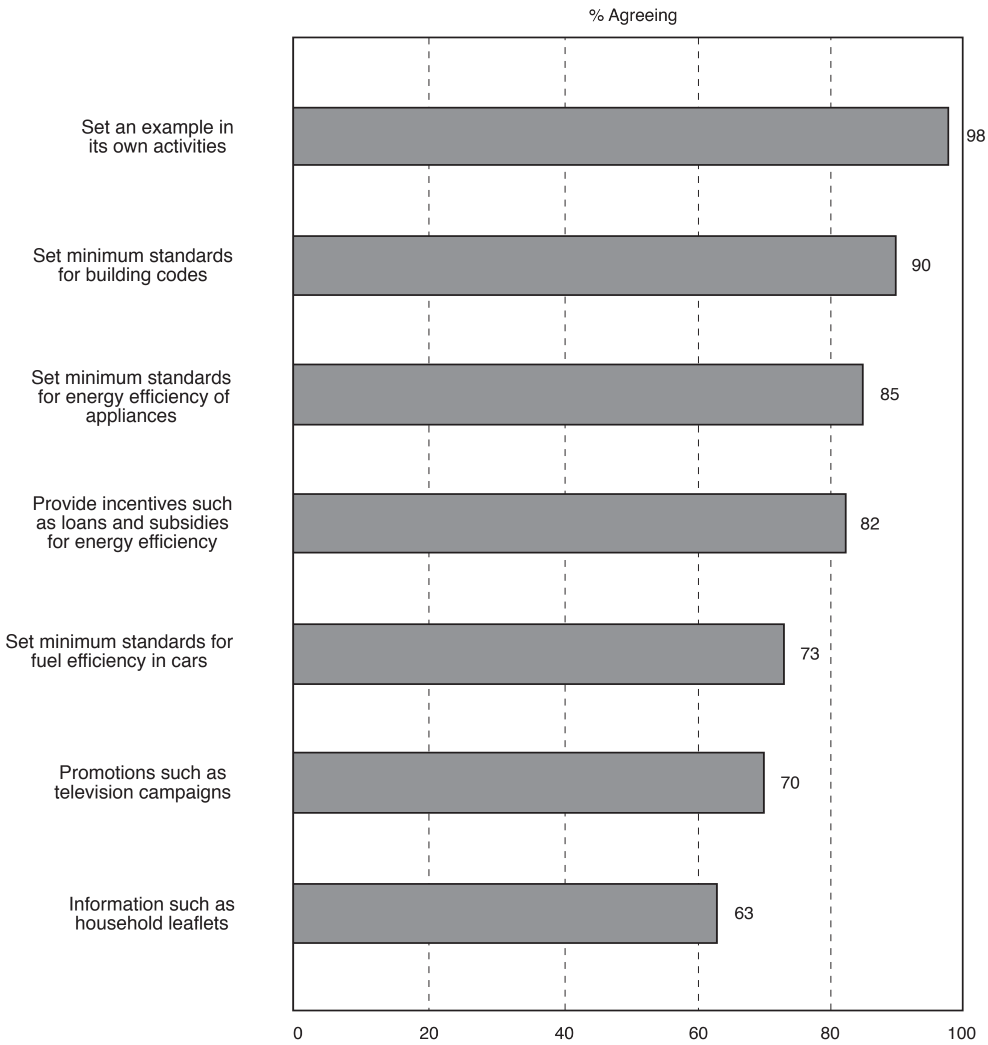


Figure 17.2: Support for government initiatives (MRL, 1993)

17.3 Priorities for the Home

The housing industry has, for a number of years, carried out surveys of the attitudes of new and existing house owners to a range of key issues. This market research aims to elicit from consumers what they wanted in a house. Consumers are faced with many trade-offs in their major purchase of a house, and an understanding of how choices are made helps to clarify some of the barriers to energy efficiency.

These surveys are conducted by asking a group of new home buyers to rank, on a scale from 1 (extremely important) to 5 (extremely unimportant) a series of features or characteristics that might be found in a home. Table 17.1 shows the responses for a selection of features (expressed as statements). Table 17.1 shows a selection of the analysis. The "rank" is how important this item appeared in the total listing of key issues. It was found that although the most important aspect of a house for all types of new house purchasers was that "the house was very comfortable". Far lower down the list came the issue of thermal insulation, and sophisticated technical control was very low.

The market survey was carried out prior to the introduction of the HERO (Home Energy Ratings Options) system. This system, developed by BRANZ for ECNZ, provides an analysis of the house, its thermal insulation, ventilation and appliance energy efficiency. Overseas experience has been that such "home energy ratings" schemes increase interest in issues of energy efficiency over time for both the house owner or purchasers and for other involved agencies, such as financiers, designers and builders.

Householders are not interested in "energy" itself, or the technology of control. They are interested in the provision of a service — warmth, coolness, light, hot water, cool foods, TV reception, stereo music, etc. People prefer to have energy efficiency as an adjunct to a service and preferably with little effort; the challenge is to provide efficient services with minimum user input.

Rank	Statement	Respondents Ranking	
		Important	Extremely Important
1	That the house was very comfortable	95.9%	57%
6	That the house was healthy to live in	88%	53%
10	That the house had high insulation rating	78%	36%
13	That temperature was easily controlled	61%	22%
25	Technically sophisticated with security sensors and thermostats	27%	8%

Table 17.1: New house statement importance ranking

People will, however, change their ways of doing things if they perceive an immediate benefit, possibly in terms of convenience, but other issues can also change attitudes and behaviour and people will make compromises. For example, the microwave oven provides speed and ease of use, but requires changes in cooking techniques and the acceptance of some changes in the type of cooking possible.

It is quite reasonable that the focus of household attention be services rather than energy use as such. An interesting point that results from market research, however, is that people often do not connect the relationship between energy efficiency and the services they value. Table 17.1 shows that while 57% of people consider a very comfortable home extremely important, only 36% consider high levels of insulation to be extremely important. Similarly, only 22% consider easy temperature control to be extremely important. Yet good insulation and temperature control are prerequisites for a very comfortable home. At face value, there is education required to help people relate their principal household service needs to the role of energy efficiency in meeting these requirements.

17.4 Variation in Resources and Incentives

Household energy use in New Zealand is dominated by electricity. This is due to its widespread availability, its relatively low cost and the fact that people generally have a positive attitude about its use in domestic situations.

About 75% of the country's electricity supply comes from hydro sources. The development of this hydro resource has been a source of national pride as the civil works required are a noteworthy achievement for a small nation. Furthermore, people viewed hydro power as a clean, non-polluting source of electricity. Starting with the Lake Manapouri debate in the 1960s, however, concern has developed over the effect of hydro development on river and lake ecosystems and landscapes. Nonetheless, the clean image of electricity through association with hydro remains.

The reality now is that most new electrical load is met from fossil fuel fired thermal power stations. While many people are concerned about the environmental implication of energy use (Figure 17.1), they do not make the connection between electricity use, thermal generation and issues such as the greenhouse effect. The only time when an effort is made to either conserve electricity or be more efficient in its use, is during periods of hydro water shortage.

The relatively low price of power in New Zealand also discourages energy efficiency, although at today's prices, there are many cost-effective energy efficiency options. If the price was higher, the range of potential efficiency options would expand. The trouble is that the price is so low that many people overlook the existing economic possibilities to improve energy efficiency. Figure 17.3 compares the residential electricity prices for a sample of 21 countries recently surveyed. New Zealand's typical residential electricity price is 3.3 times lower than the highest of the 21 countries surveyed (Belgium). The price of residential power in New Zealand is approximately half that of the average of the 21 countries.

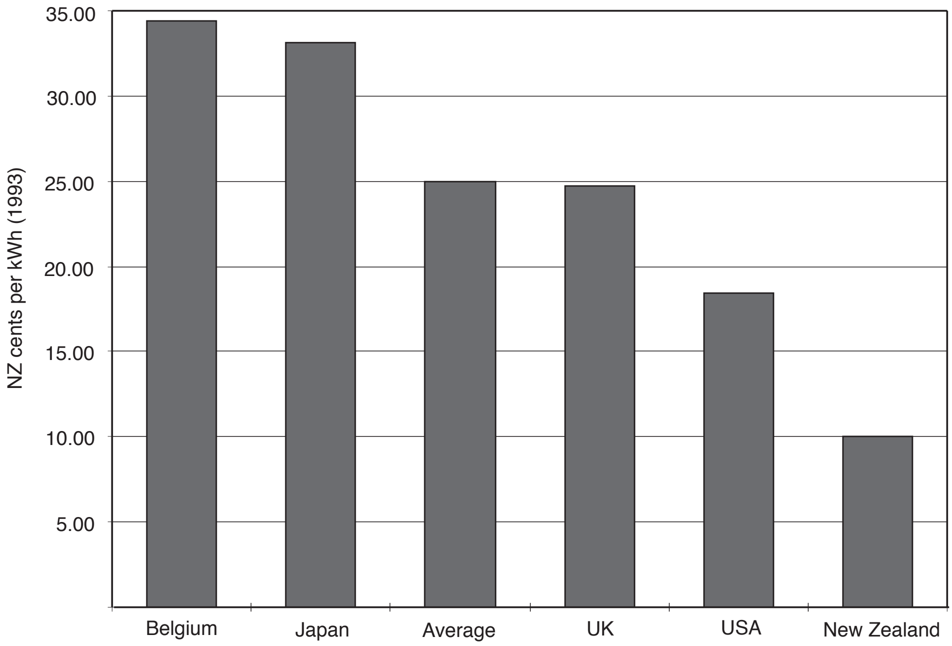


Figure 17.3: Residential electricity prices in New Zealand and overseas (Energy Economist, 1993)

In the past, New Zealand has paid the average cost of generation rather than the (normally) higher marginal cost. Furthermore, this average cost had a degree of taxpayer subsidy built into it. Reform of the electricity market is likely to eventually see consumers being charged at rates nearer to marginal costs. Taxpayer subsidies will be a thing of the past, although an element of subsidy will remain entrenched in the valuation of some state assets managed by ECNZ; the Clyde Dam cost $1700 million to build, but the power is presently being charged as if it only cost $800m. Building in environmental levies (for example a carbon charge on fossil fuels) to reflect the full social cost of power generation would see power prices rise further.

While increased power prices may draw household attention to energy efficiency opportunities, it introduces a problem. Many households, namely those on low incomes, may only be able to respond to higher prices through behaviour changes and conservation rather than investment in efficiency hardware. These people may have great difficulty finding the capital for such investments as home insulation, even though a home economics study may show that this would improve the family finances. Access to reasonably-priced finance is a major issue. One possibility is for the local power company to fund certain proven investments (such as cylinder wraps) and recover the capital and interest via power bills.

Many low income families are in rental accommodation and this exacerbates the already unequal access to energy efficiency. It may not be in the family's interest to fund non-chattels, that is improvements that cannot be taken when the family moves. The landlord has no incentive to invest in house improvements, such as insulation, as the resident family pays the power bills. Potential sources of finance (lenders) for the family find it difficult to secure their lending in these cases. This situation is a case of market failure. Solutions include building codes that require upgrading of old residential buildings, sources of capital for low income families, and community action to encourage people to group together and share resources and skills.

17.5 New Zealand Housing Industry

The housing industry is fragmented, with different influences on different sections. A schematic overview is provided in Figure 17.4. The primary split is between the new house market and the market for renovation and retrofit. Although the number of new homes grows by almost 20,000 per year, there are over a million existing houses.

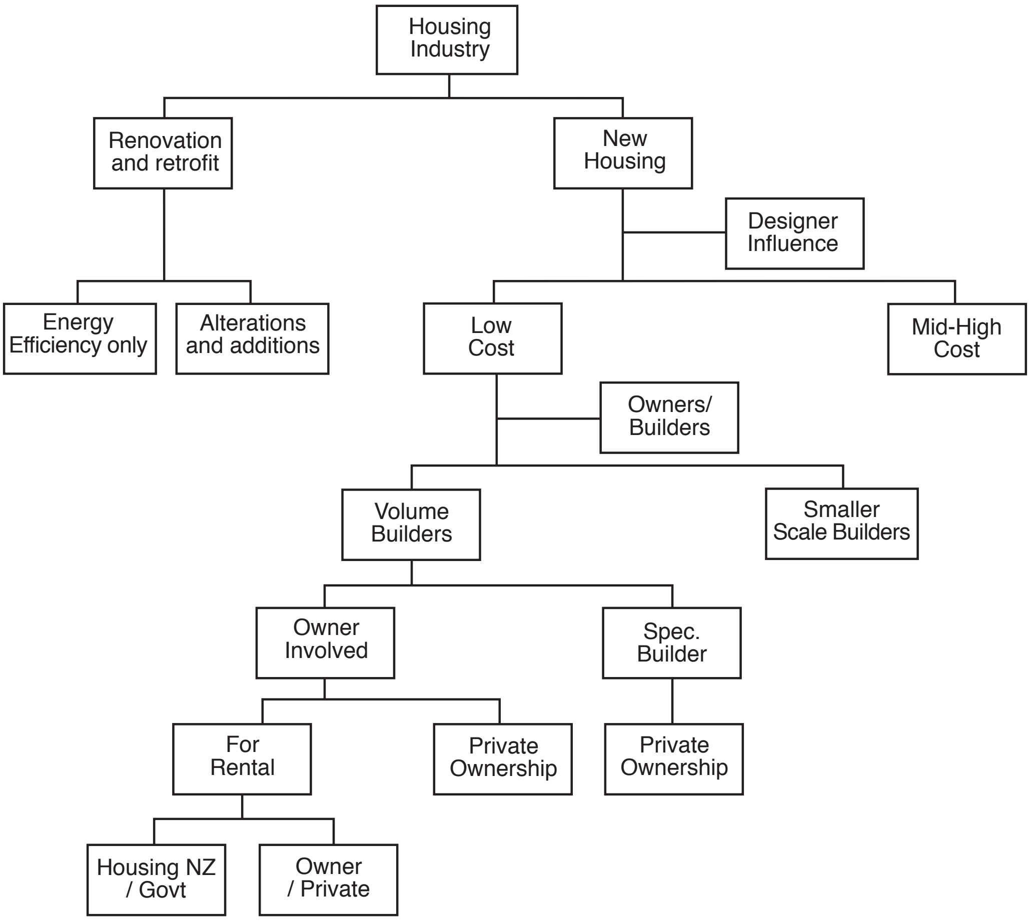


Figure 17.4: Housing industry sections

New House Market

The new house market varies from year to year and covers a wide range of sizes and prices. Approximately 18,000 new dwelling units were built in the year ended June 1993, with a total value of $1925 million.

About one-third of new houses are built by large housing companies; about the same proportion is built by private builders, and the majority of the remainder by "labour only" contract or the future owner. The proportion of houses built for an unspecified future owner ("spec" built) has decreased dramatically over the past five years, falling from nearly one-third of new houses to just over one-tenth.

"Spec" houses can have a major impact on market direction as the builder often includes special features to attract market attention. Prospective new home buyers see what is possible and start demanding it for their own homes. This influence may be more significant than the ability of designers (architects, architectural draughtspeople etc.) to implement new and energy efficient ideas through large housing companies or individual clients.

Figure 17.5 illustrates how house buyers now expect to have an input into their new house design. The proportion of buyers merely accepting the builder's plan has fallen from 38% in 1987 to 17% in 1993. Although the proportion of house buyers modifying the builder's plans has increased, the largest growth has occurred where the new owner is actively involved in the new design — either alone or through the use of an architect. This trend may be helpful. If people are prepared to take an active interest in the design of their home, then they may be receptive to energy efficiency information. The greater involvement of architects also means that this group needs to be a target for information.

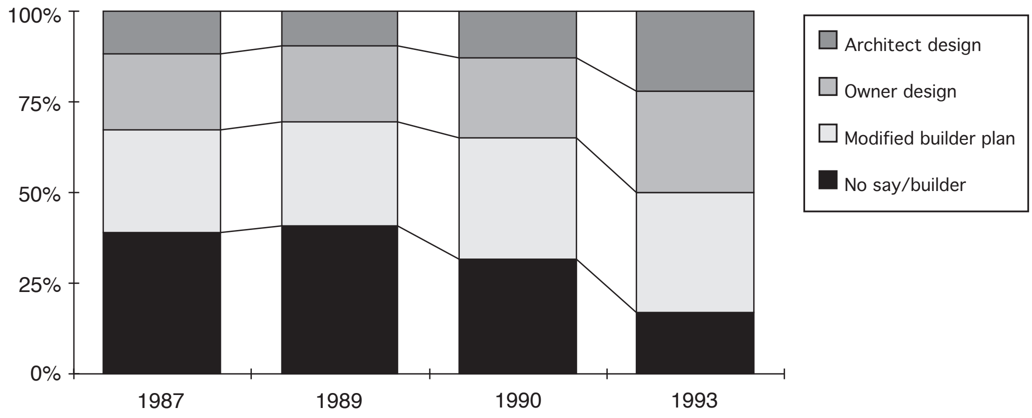


Figure 17.5: Selection of house designs

In new buildings, the marginal cost of an energy efficiency feature may not be great whereas in a retrofit, short of a major renovation, the full cost of the feature must be considered. Nonetheless, even when the marginal cost may not be great, its acceptability and impact cannot be evaluated in isolation, as the cumulative impact of a range of changing requirements must also be considered.

The cumulative additional costs may be unacceptable in certain sectors of the housing market. For example, a small (say $100) increase in the base cost may affect a potential purchaser's ability to pay for a low-cost house, but be of less concern in the higher-priced house market. An individual housing company incorporating significant energy efficient features may result in their repositioning in the market. The new house market is very competitive, and in today's market many decisions are often made on first (capital) cost and appearance, rather than on hidden features such as energy efficiency.

Renovation/Retrofit Market

Whereas for a sizeable proportion of new houses the final owner is not established at the time of commencement of construction, this is not the case for renovation and retrofit. This market is valued at approximately $3 billion annually, and just under two-thirds of homeowners have made an expenditure for renovation or retrofit within the past year. A similar proportion intend to undertake work in the next year. The mean expenditure is just over $3000, with just over one-third of the annual expenditure consisting of investments less than $1000.

The renovation market may be split into projects involving solely "energy efficiency" activities (e.g. installation of insulation) or "general alterations and additions", which may in part include energy efficiency (e.g. adding a new room that includes energy efficient features). The market for major work (that requires a building permit) is far smaller than minor work (e.g. repainting).

When energy efficiency can be added as a marginal option, then information as to the availability of product, and the desirability of the actions are both important. For example, if an exterior wall is to be rebuilt due to decay, the marginal cost of installing additional insulation is small. If the sole purpose for cutting into the wall is to install insulation, the cost is high.

There must still be questions as to whether or not a house purchaser will undertake a rational economic analysis before commencing work. It is not clear whether or not a householder carrying out renovations compares the cost of installing an energy efficient feature with the net present value of the energy saved over the feature's lifetime. The householder may, in fact, be influenced as much by the initial costs (if it is a small additional cost then the work proceeds) or other non-economic but still tangible benefits. For example, the comfort benefits from improved insulation may be more important than any energy cost savings.

17.6 Public Policy Response

The public responses to one of the issues covered by the MRL survey (the top proposition in Figure 17.2) could be interpreted to mean people are not happy with the level of leadership government is showing on energy efficiency. Steps have been taken by government and local authorities to put their own house in order. Action on energy efficiency is now one of the performance criteria for CEOs of government departments. A survey of 68 government agencies and local authorities showed that 41 had undertaken an energy audit and 38 of these had taken action as a result of the audit (MRL, 1993).

However, more needs to be done to show leadership. A particular concern is the apparent low priority assigned energy efficiency by Housing New Zealand when drawing up specifications for major renovation projects. The country's major provider of rental housing for low-income families should set an example for private sector landlords.

Present public policy on energy efficiency requires upgrading. The building code for residential buildings does cover insulation but, as noted in Chapter 1, the requirements fall below those of many other nations. Furthermore a more sophisticated system is required that covers windows, passive solar gain, geographic location, etc. The code is currently under review and there is some promise of a better system in the future (for more information on the building code and its revision see Chapter 8 in Part 2: Commercial and Institutional Buildings).

One of the matters that undermines the use of building codes is inconsistency in their application.

- There is a discrepancy between the requirements for residential domestic buildings and commercial buildings under the Building Code. The industry may well be concerned that if energy efficiency is so important, why does it not apply equally to all building types?
- If the capital cost of new buildings can be increased by enforcing energy efficiency requirements, then why is it not necessary to undertake action in the many more existing buildings?

A case can be made for gradually applying standards to old buildings, starting with ceiling insulation. Where renovations require a building permit, insulation of external walls could be required and enforced. The people that favoured the use of the Building Code (Figure 17.2) may not, of course, have envisaged they would be required to place batts in their home. The political dimension of expanding the coverage of the building codes would need to be skilfully managed.

There is public support for minimum energy performance standards (MEPS) for appliances, space and water heaters, but to date no mandatory standards exist. MEPS are under investigation by EECA. There is a need to work in with Australian authorities on this matter (due to aim of harmonising regulations under CER). The efficiency of many appliances manufactured for domestic use in New Zealand is well below that for the United States and Europe. Urgency should be attached to a programme of progressively developing and implementing MEPS for a range of equipment. In terms of energy use and efficiency potential, electric water cylinders and ancillary equipment such as shower heads, should be a priority.

Through EECA, progress is being made to overcome barriers to household energy efficiency. Government funding of EECA has increased each year since the organisation's inception and the revenue from the Crown for operating expenses is currently around $5.5M. A fair share of these funds are used for programmes covering household energy efficiency as distinct from energy use in other sectors. The hot water programme is an example, and this involves a public media campaign underpinned by work with trade suppliers, plumbers, power companies and other stakeholders.

As part of a package of measures to encourage the gradual development of a competitive wholesale electricity market, the Government has also established the Energy Saver Fund to foster residential energy efficiency over a five year period. This fund amounts to $16.5 million of contestable monies and $1.5 million to cover administration of the scheme by EECA (the first year's administration costs of around $300,000 are part of the $5.5 million operating budget for EECA mentioned above).

This Energy Saver Fund is intended to provide a transition to a mature electricity market in which (it is hoped) competition will be based on provision of energy services, including efficiency as well as energy price. The funds will be allocated by tender. A wide range of organisations and bodies could compete for the funds. This policy may provide (among other things) a means for community groups to obtain resources to assist low paid families fund energy efficiency investment.

In addition to public policies on energy efficiency, it is important to recognise the role of power companies and other commercial entities in energy efficiency for domestic buildings. In some countries, Norway for example, power companies are required to spend a set proportion of their revenues on promoting energy efficiency. In the United States, so-called demand-side management must be carried out by power utilities.

Here in New Zealand, action is not mandatory, but nonetheless power companies promote energy efficiency to varying degrees. In some areas, such as in part of Southpower's distribution area, one of the motivations for efficiency is to reduce the need for new investment in line capacity. In such cases, energy efficiency is vigorously promoted to households. In other cases there is a suspicion that the involvement of power companies in energy efficiency promotion is more for marketing reasons. Time will reveal the long-term involvement and effect of power company activity in this area.

Finally, it is important to recognise the work of community groups in energy efficiency. There is an established group in Christchurch and a trial project for community involvement in Cannons Creek, Porirua. These initiatives receive some local authority and/or power company and EECA support, but not enough to cover all outputs. Individuals are investing their own time, effort and resources. The lessons from these community-based initiatives could enable further groups to form and grow. Some of the new Energy Saver Fund monies should be targeted at these groups to achieve greater equity in access to energy efficiency opportunities by families.

17.7 Changes in the Past Decade

A good place to end is to take stock of where the country has been and how far it has moved on energy efficiency. It is worth reviewing a study carried out in 1980 that investigated the barriers to energy efficiency (Isaacs et al., 1981). That study examined buildings per se rather than just lighting and appliances. Barriers then included (with changes since the time of the study in parentheses):

- historical and social expectations;
- rigid adherence to overseas designs (New Zealand has since developed its own architectural and building styles, but there is still an enthusiasm for overseas experience);
- aesthetic and/or architectural emphasis e.g. southerly view without compensating for energy consequences with, for example, double glazing (no change);
- conventional quarter acre section has the living room facing the road and the kitchen hidden at the back (there has been a shift to smaller plots and interest in "solar" orientated subdivisions, but this is by no means universal);
- lack of governmental awareness or enthusiasm for energy efficient design (some change with the Building Code and increased emphasis through EECA, but more still needs to be done);
- lack of information and data specifically for New Zealand situations (there are now information publications from Ministry of Commerce, BRANZ, Victoria University of Wellington, etc, and during the 1980s some practical demonstrations. The BETA awards, even with their focus on electricity, offer some encouragement. The HERO scheme has been developed).

The 1980 study also noted that until the marketplace was working with passive solar design, many of the issues found overseas e.g. legal barriers such as the right to sunlight, would not emerge. In that example, the Town and Country Planning Act 1977 explicitly provided the right to territorial local authorities to plan for access to sunlight (Isaacs and Donn, 1987). The Resource Management Act (1991) instituted major change in land planning legislation that has yet to be clearly understood or implemented at a local level with respect to its consequences on passive solar design.

However, there are examples starting to come through in discussion documents from local authorities that suggest that new planning schemes will be far more flexible and will allow for improved energy efficient design both of allotment layout and housing.

The future is uncertain, but offers some promise. There have been positive changes in energy efficiency attitudes over the last decade. Between EECA, power companies, community groups, the building industry and research organisations there is now considerable skill and the presence of motivated teams that will advance household energy efficiency further.

References

Eden Resources Ltd (1993). *Renewable Energy Opportunities for New Zealand — Executive Report*, prepared by Eden Resources Ltd for the Ministry of Commerce, Wellington.

Energy Economist, September 1993 143/25

Isaacs, N and M Donn (1987). *Sunlight Access Provisions in the Town and Country Planning Act 1977 and Options for the Future School of Architecture*, CRP 46, Victoria University of Wellington.

Isaacs, N, L H Jeffs and J D Hocking (1981). *Barriers to Small Scale Energy Technologies in New Zealand*, NZERDC Report, 59.

MRL (1993). *Attitudes Towards Energy Efficiency*, report by MRL Research Group to EECA, Wellington.

Resource Management Act 1991, New Zealand Statute, Government Printer, Wellington.

Town and Country Planning Act 1977, New Zealand Statute on land use and environmental planning superseded by the Resource Management Act 1991.

Contributing Personnel

Contributing personnel to the Domestic Buildings Task Group were:

Mr Mark Bassett, BRANZ, Wellington (Leader)

Mr Mark Ashford, Fletcher Duroid, Auckland

Mr Nigel Isaacs, School of Architecture, Victoria University of Wellington

Mr John Patterson, Group Energy Consultants, Auckland

Dr Alan Tucker, Department of Mechanical Engineering, University of Canterbury

Mr Gus Watt, Watt Architects, Lower Hutt

Mr Tony Gregory, Rinnai NZ Limited, Auckland

Mr Keith Cullum, Housing Industry Association, Auckland

Mr Martin Greenhough, NZ Fibreglass, Auckland

Mr Graeme Worthington, Electrical Development Association, Wellington

Mr Gordon Vickers, EECA, Wellington

Mr Val Korelev, Coal Research Association of New Zealand, Lower Hutt

Mr Lindsay Roke, Fisher & Paykel, Auckland

Professor Arthur Williamson, Thermocell, Christchurch

Mrs Lynda Amitrans, BRANZ, Wellington

Part 2

Commercial Buildings

Contents of Part 2: Commercial and Institutional Buildings

Chapter 1
Commercial and Institutional Buildings Overview

1.1 Introduction

Modern societies have a large amount of accumulated wealth tied up in commercial and institutional buildings and the supporting infrastructure (roads and utility supplies). Institutional buildings range from multi-storey university and hospital buildings, to smaller residential-scale schools and community centres. Commercial buildings similarly range from large office blocks, retail complexes and hotel accommodation to small shops and workshops.

The main focus in this part of the report is the use of energy in larger buildings (with a floor area of around a thousand square metres or more). Some of the material presented here will, however, be relevant to intermediate and residential-sized commercial or institutional buildings. Much of the material in Part 1 of this report "Domestic Buildings" will be relevant to these smaller buildings, and some of it, the lighting and glazing sections, for example, are also quite relevant to large buildings. Parts 1 and 2 of this report are complementary and are cross referenced where appropriate.

This chapter starts with an overview of the commercial/institutional buildings sector. The use of energy by different components of the sector and by different building energy services is outlined. Section 1.3 discusses the potential for energy efficiency improvements in the sector. The importance of building-in energy efficiency at the outset is emphasised. Most buildings, however, also have energy efficiency retrofit potential, especially during major refurbishment.

Section 1.4 outlines the technologies that could be used to improve building energy efficiency. In effect, this section provides an overview of the contents of the other chapters of this part of the report. The rationale for covering the chosen topics is briefly explained and the key points that come out of each chapter are highlighted.

1.2 Sub-sector and Services Energy Use

The operation of commercial and institutional buildings accounts for the direct use of about 18.4% of New Zealand's electricity and 5.3% of its fossil fuels (Ministry of Commerce, 1993). The materials used in the construction, refurbishment and maintenance of these buildings require energy for their production, transportation to site, erection and eventual demolition. This energy requirement accounts for part of the energy use of the industrial and transportation sectors serving the construction industry. Although the energy embodied in buildings is significant and reducible, the focus here is only on opportunities to reduce the energy used to operate them.

In 1990, the sector contained over 42,000 buildings totalling some 41 million square metres of floor space. It can be conveniently subdivided into five sub-sectors, each having a broadly related group of activities, as shown in Table 1.1 (Baines and Brander, 1991).

The commercial sector's floor area and energy use is concentrated in the larger buildings; just 345 buildings over 10,000 m^2 in the health, education and office subsectors account for 24% of the sector floor area and probably about 30% of electricity use.

The energy intensity and end use distribution varies widely between the subsectors. Table 1.2 provides an estimate of annual energy end use for hypothetical buildings located in Wellington with standard hours of occupancy. The numbers refer to useful energy for each end use, not delivered energy, and do not allow for plant efficiencies (heating input energy, for example, will depend on whether natural gas or electric resistance or heat pump plant is used) (Energy Research Group, 1989).

Office buildings are divided into two categories, those where the internal load (e.g. lighting and equipment) dominates the energy balance (ILD), and those where energy movements across the shell or skin dominate (SLD).

Sub-sector	Area 10^6 m^2	Electricity (TJ)	Fossil Fuel Use (TJ)
Health	2.96	1903	3400
Education	8.14	1604	2274
Offices	16.17	4294	2663
Accomodation	4.52	2630	793
Retail/Wholesale	9.38	4708	1228
TOTAL	41.17	15 139	10 358

Table 1.1: Energy use in commercial subsectors

End Use		Heating	Cooling	Lighting	DHW	Equip.	Total
Building type		MJ/m^2/yr					
Offices	ILD	175	25	175	10	75	460
	SLD	240	10	175	10	15	450
Schools	primary	250	-	55	5	40	350
	secondary	250	-	55	5	40	350
Tertiary		250	-	100	10	220	530
Hospitals		850	80	150	200	425	1705
Shopping Centres		45	25	285	5	20	380
Barracks/Dorms		550	-	100	175	200	1025
Warehouses		10	-	15	-	-	25

Note:
- a. Heating — the provision of heat within the building
- b. Cooling — the provision of cool air within the building
- c. Lighting — the provision of artificial illumination within the building and its immediate surrounds (not including carparks)
- d. DHW — the provision of hot water for general (non process) use within a building
- e. Equipment — includes the miscellaneous services provided by fans, lifts, pumps, steam plant and office machines (not including central computers)
  — the distribution of heat and cooling (a,b) is covered by equipment

Table 1.2: Useful energy by end use for different buildings

As can be seen in Table 1.2, lighting and airconditioning (including heating, cooling and distribution equipment) are major end uses in offices. Domestic hot water (DHW) is a major use only in hospitals and residential institutions. Energy intensities, as measured on a floor area basis, vary from a high of 1705 MJ/m^2/yr for hospitals to a low of 25 MJ/m^2/yr for warehouses.

1.3 Potential for Energy Efficiency Improvements

Energy efficiency in buildings can be increased by attention to building design (including construction and commissioning), use of new technologies and the practice of sound management techniques.

In the short term, refurbishments, retrofits and improved management of existing buildings will offer the greatest opportunity for increasing energy efficiency in the sector. In the longer term, energy efficient design will become increasingly important. It has long been recognised that most of the potential for increased energy efficiency is realised at the design stage. This can be inferred from the 1982 "New Zealand Code of Practice for Energy Conservation in Non-residential Buildings" (NZS 4220:1982), which sets targets for new buildings at about half the energy intensity targets for existing buildings.

A 1989 estimate of energy efficiency potentials by end use, obtained from surveys of existing building stocks in the late 1970s and early 1980s, is shown in Table 1.3 (Energy Research Group, 1989). The numbers are multiplied by the useful energy figures in Table 1.2 and other factors to take account of climate, plant efficiency, occupancy and work shift patterns to generate a target energy use.

End use	**Heating**		**Cooling**		**Lighting**		**HWS**	**Equip**
Construction	ILD	SLD	ILD	SLD	Deep Plan	Norm Plan		
New Building	0.6	0.5	0.7	0.8	0.65	0.5	0.9	0.8
Existing Building	0.85	0.75	0.85	0.95	0.75	0.6	0.95	0.9

Note: ILD = internal load dominated building (e.g. > 5000 m^2)
SLD = skin load dominated building (e.g. < 5000 m^2)

Table 1.3: Estimates of energy saving potentials in buildings

The value 1 represents the average performance of existing buildings. All the factors in Table 1.3 are less than one, indicating that improvements can be made. As can be seen from Table 1.3, the values for new buildings are substantially lower than for existing buildings. For example, the target for heating in new buildings of 0.6 (internal load dominated) is 29% less than for existing buildings of 0.85. These targets have been developed without reference to implementation costs or cost effectiveness. Instead they represent consumption figures bettered by a fixed fraction of buildings existing at the time of the surveys. To a degree, they represent the best practice in the sector.

More recent experience indicates that the cost-effective potential is significantly higher, particularly in the USA. The use of energy efficiency design assistance throughout the design process can yield savings of up to 75% prior to construction. Typical savings available from expert design assistance, through each stage of the design process, are shown in Figure 1.1 (Bishop, 1994). As can be seen, the greatest savings occur in the early stages (the percentage savings are compounded rather than additive).

Some caution is required in applying these results directly to New Zealand since energy prices, climate and the cost of technologies, for example, differ from the USA. Nonetheless, it is believed that the cost-effective potential in New Zealand will not differ substantially from the US findings. One reason for this is the rather poor quality, in terms of energy efficiency, of our commercial building stock, which is not subject to any mandatory energy efficiency standards. Another reason, given our temperate climate, is that computer-based thermal modelling can demonstrate the lack of need for airconditioning that would otherwise be installed based on the "rules of thumb" used by building services engineers (see the Nelson City Library example in Chapter 9 "Case Studies").

Where energy efficiency measures are incorporated into a major retrofit or a refurbishment that is being carried out for other reasons, the potential for cost effective energy savings can approach that for new buildings. Where retrofits are driven by the desire to improve energy efficiency and reduce costs, the numbers in Table 1.3 for an existing building indicate end-use energy savings of 15% to 25% for heating, and 25% to 40% for lighting.

1.4 Energy Efficiency Technologies

This section provides a brief introduction to the chapters that follow. Chapter 2 deals with the building envelope and form. It traces the evolution of architectural approaches to the issues of space conditioning and lighting. By moving to sustainable architecture, designers are now turning full cycle. With careful design, it is possible to provide buildings that are pleasant to work in, have high levels of natural light and a degree of passive ventilation. A work-with-nature approach rather than complete reliance on superimposed HVAC systems could save substantial amounts of energy.

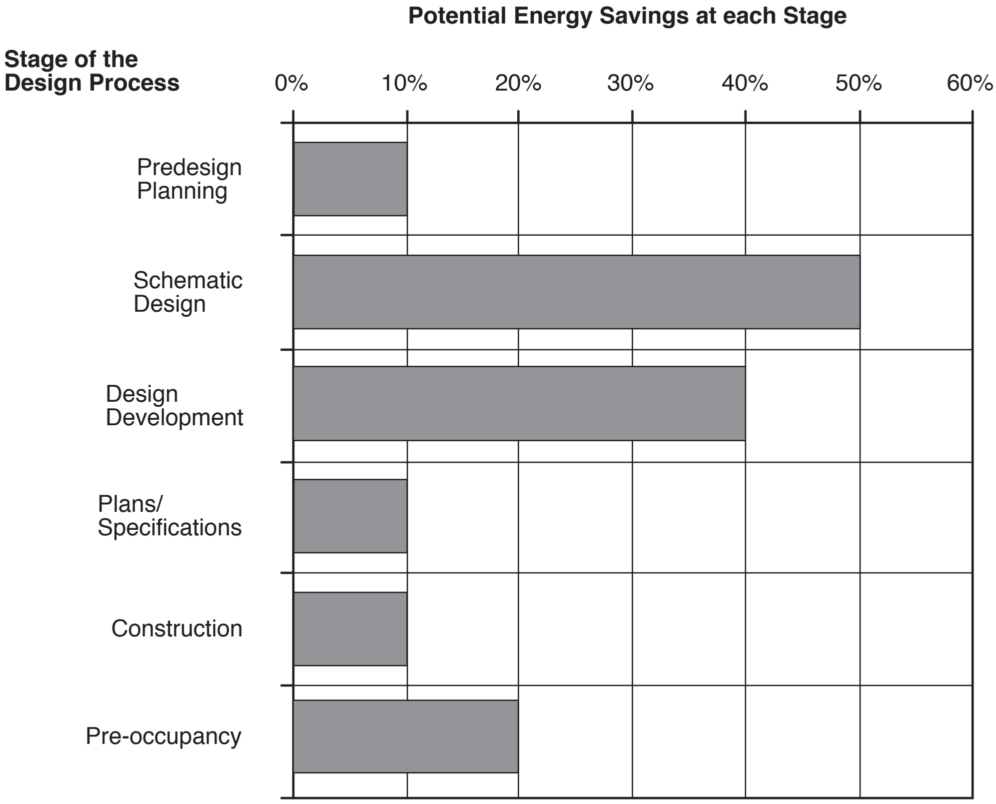


Figure 1.1: Potential energy savings at each building stage

Lighting is arguably one of the most important energy aspects of modern buildings and is covered in Chapter 3. Artificial lighting invariably uses electricity, an expensive form of energy. The heat from inefficient lighting adds considerably to HVAC loads. A range of energy efficient technologies are available encompassing efficient fluorescent tubes, reflectors, electronic ballasts and controls. A modern, energy efficient lighting retrofit can perform so well that in many cases it is commercially viable to scrap existing lighting systems, even if they still have some useful life left.

Chapter 4 covers HVAC systems. Again, the importance of reducing internal heat loads such as lighting is emphasised. The use of cool outside air is also an important energy efficiency tactic wherever possible. No single technology stands out in the HVAC area. Substantial gains can be made by a combination of equipment and practices: increasing the size of heat exchangers, correct maintenance, good choice of motors and fans, effective duct sealing, use of computer controls, etc.

Chapter 5 is quite important as it covers a major growth area: the use of office equipment. As well as drawing electricity, and requiring greater building wiring capacities, equipment also adds to the heat load. A wide range of energy efficient technologies are becoming available. These include cold fusing printing devices and low energy computer screens. Office workers can play a useful role by turning off their PCs when they leave their workstations.

Chapter 6 "Management, Monitoring and Targeting" explains the importance of developing an energy management programme for a commercial building. This programme should lead to energy use targets actual demand should be measured against. Computerised building energy management and monitoring systems are playing an important role in effective implementation of energy management programmes.

One of the problems with current building design practice is that the building envelope and form and the lighting and HVAC systems are the domain of different professional groups. Chapter 7 "Modern Building

Design Tools" discusses the development and application of computer simulation tools that enable the integrated design of buildings. These tools can facilitate greater professional interaction and the optimisation of such matters as building thermal mass, glazing and HVAC performance.

There are significant barriers to improving the energy efficiency of commercial buildings. These are discussed in Chapter 8. In many countries, a common response to these barriers is the development of building energy performance standards. The present New Zealand situation regarding building codes and energy use is outlined, and issues that need to be addressed in developing commercial standards for this country are discussed.

While there are barriers, some building developers or owners have had the foresight to overcome them. Chapter 9 ends the material on commercial buildings with a series of success stories. Ten case studies are presented that show how energy efficiency has been improved. In each case, not only have there been commercial benefits, but also the services provided by the building have been enhanced. The results include better lighting, more comfortable surroundings, a more productive work environment or something as basic as a steady hot shower in an accommodation building.

The material presented on commercial buildings is not comprehensive. Information on hot water systems is not presented, except for one case study. While HVAC is covered, space heating from small appliances is also not mentioned. Part 1 of this report "Domestic Buildings" contains much useful information for the commercial building manager, especially those who are responsible for smaller buildings (300 m^2 to 500 m^2). It should be read in conjunction with the material on commercial buildings.

References

Baines, J and W Brander (1991). *Energy Efficiency Markets 1990-2005*. ECNZ, 1991.

Bishop, R (1994). Pers. comm. quoting Keneipp et al. (1990). *Developing Demand Side Programs for Commercial/Industrial New Construction Projects*, ACEEE Summer Study 1990 Proceedings, Vol. 8 Utility Programs, American Society for an Energy Efficient Economy, Washington DC.

Energy Research Group (1989). *Building Energy Performance Targets*, Workbook prepared for Works and Development Services Corporation, School of Architecture, Victoria University of Wellington.

Ministry of Commerce (1993). *Energy Data File*, Wellington.

NZS 4220:1982, *New Zealand Code of Practice for Energy Conservation in Non-residential Buildings*.

Chapter 2
Building Envelope and Form

2. 1 Introduction

Commercial and institutional buildings, and the supporting infrastructure, represent a significant portion of the accumulated capital stock. Together, they represent the principal life support systems for the future. The way commercial and institutional buildings are built, used, and refurbished will have a significant role to play in the future sustainability of cities. Among those who consider such issues, the need for cities to become more sustainable raises little argument. The means of achieving this, however, is debatable and readers should note that this chapter presents just one particular point of view.

This chapter starts by looking at commercial buildings in the wider context of the changes that need to be made to cities to make these more sustainable, especially in terms of energy use. It then moves on to examine the trend towards more sustainable architecture and places this trend in an historic context. Sustainable architecture requires working from a new set of paradigms and aesthetics. The means for giving practical expression to sustainable architecture are outlined.

There has been a worldwide trend in recent decades for commercial buildings to be designed to be reliant on mechanical systems to produce acceptable internal comfort conditions. The resulting buildings, while producing uniform (if not boring) internal environments, were heavily dependent upon fossil fuels and other nonrenewable resources. They were inherently nonsustainable and inefficient in their use of energy. In addition, toxic emissions from building materials often led to indoor air quality health issues.

Global concerns about carbon dioxide emissions is a factor of increasing and critical importance, which suggests that existing attitudes cannot continue. To disregard the sustainability issue is, perhaps, to threaten society's future on Earth [1].

Any move to a sustainable future, perhaps requiring carbon dioxide emission reductions of 60%, will demand more than just "energy efficient" buildings. Changes to the basic form of the buildings will be necessary, along with wider considerations of city infrastructure. Close proximity of place of residence and place of work will be essential, which will lead to a change in the basic one-use characteristic of the "commercial building".

A new breed of commercial buildings will, therefore, be important in this sustainable future. Commercial buildings contribute significantly to the emission of carbon dioxide and other greenhouse gases throughout their first usable life, including their construction stages. They certainly cannot be ignored in any exploration of the connection between the built environment and climate change [2]. Any response that aims at a sustainable future will only be successful if the commercial building sector is investigated and modified. The overall energy efficiency and conservation performance of individual buildings will be important.

The external skin configuration of the commercial building type is a key contributor to the overall success, or otherwise, of achieving the required aim of a "sustainable" built environment. The design of this external skin requires not just technological skill on the part of the designers involved, but also a clear understanding of the underlying aesthetics of sustainability. A new building form will result, which may well draw heavily on historical patterns from the pre-modernist period.

2.2 Wider Sustainability Considerations

Until recently, the use of nonrenewable forms of energy was of limited concern and cities tended to be designed around the movement of people and goods. The wasteful environments so produced are increasingly an embarrassment in terms of a sustainable future.

The way cities are used must change. The sustainable city of the future must be a low-movement city [3], a city that allows an exciting way of life without the polluting and resource-consuming patterns required by the movement of people and goods. The modification of the infrastructure of the total city is necessary including suburbia and the downtown regions. Existing suburbs must change. Rather than more housing in the suburbs, other commercial uses should be developed so that the need to travel large distances on inefficient transport systems is reduced. Most of the daily needs of employment and recreation will be available closer to places of residence in the sustainable city of the future.

The central business district (CBD as it is called at present) must also change. All the other functions, besides offices, necessary in a lively, healthy city must appear. The one-use office building of recent times is likely to become less of a norm in future decades. Residential and other uses must return to the downtown regions if sustainable cities are to evolve. The majority of this housing can be provided within the existing infrastructure of buildings or unused office towers. While new uses for surplus buildings must be found, some modification must also take place to make them acceptable to a more aware, consuming public. As well as offering uses that respond to the needs of real people, they must also be healthy and non-toxic and offer the occupants an opportunity to control their own environment.

As the environmental and energy conservation awareness of the general community grows, buildings will increasingly be seen as a resource to be conserved and modified to produce new sustainable uses. The way commercial buildings are built, used and refurbished is a critical factor in this commitment. The throw-away, toxic-consumer architecture of the recent past is no longer ecologically or morally acceptable. Cities will become better places. Changing work patterns and the low expectation that “work”, as known in the 1970s and 1980s, will exist in the future will hasten this need for change. Commercial buildings and the associated design considerations are at the heart of any change. Wider sustainability issues may be increasingly seen as driving energy efficiency approaches.

2.3 Agenda 21 Demands

This document, seen by many as the most important outcome from the June 1992 Earth Summit in Rio de Janeiro, includes a wide range of possible demands on the users and producers of the built environment, including commercial buildings [4]. Aspects of resource conservation and energy efficiency are paramount. The short-life, resource-consuming architecture of the recent past (so well portrayed in the commercial building sector) is no longer sustainable.

Agenda 21 recognises that a sustainable future, in terms of the wider community and those specifically involved in the production and management of commercial buildings, must involve at least three basic shifts in social operation:

- At all levels, people must be better educated to be aware of both global and personal environmental threats and the possible responses.
- The governments of the world must legislate, to a degree, to create certain minimum standards. The free-market approach fails to recognise that many of the environmental threats are related to different timescales from those associated with the main controller of the market — the six month to three year horizon of the business world.
- Society must provide the overall incentives for individuals and corporations to respond to the environmentally-friendly philosophies needed. These incentives may be financial, but can also appeal to other human needs.

Architects have too often ignored the needs of the wider society in producing short-term financial gains for clients yet Agenda 21 can be seen to demand those producers of the built environment to consider the wider environment, not just that related to a specific site.

Overall, the prospects inherent in this sustainable built environment of the future are exciting and consumer friendly, suggesting a new form of commercial building.

The generally accepted summary of actions necessary from Agenda 21 include steps:

- to encourage the development and use of renewable energy in buildings and throughout the built environment system;
- to encourage, and perhaps demand, the construction of buildings that use low levels of nonrenewable energy in all phases of their manufacture, construction, use and disposal;
- to encourage the re-use and recycling of buildings, building components and building materials over long periods of time;
- to encourage local complementarity of built environment components and facilities, which will lead, in time, to reduced transport demand, including residential infill in central business areas and commercial infill in existing residential areas;
- to encourage the development of environment-friendly technologies that would be welcomed as neighbours to facilitate greater complementarity and uses, residential and commercial;
- to encourage the continuing development and widespread availability of computing and telecommunications for information exchange without movement of goods and people; and
- to encourage technologies and management techniques that help bring the various components of life-supporting systems closer together, such as:
  - — the local use of organic wastes for fuels, thus avoiding the release of methane from landfills or other waste disposal;
  - — local systems for harvesting and recycling water and wastes; and
  - — using every available area for productive purposes, including energy harvesting and urban food production.

Overall, Agenda 21 demands are wide ranging, but they are possible and are certainly necessary.

Architectural approaches and philosophies are changing because of the absolute need for the producers and owners of commercial buildings to respond to global pollution concerns [7]. The proportion of total energy use attributable to buildings generally ranges from upwards of 40% in countries such as the UK and the USA, 30% to 35% in OECD countries generally, to as low as 10% to 15% in non-industrial, undeveloped countries. The direct connection of this energy use and greenhouse gas emissions in various countries is determined by the type of energy production systems, ranging from relatively "clean" hydroelectric generation to heavily-polluting, coal-driven systems.

2.4 Architectural Change

The development of any new architecture, such as that related to sustainability or energy efficiency, demands a new aesthetic. If the comparable development of modernism is analaysed, there are many similarities. With modernism, the first developments were of a technological nature and the aesthetic of modernism followed. The sustainability movement may well expect similar developments.

The most dominant force of sustainability is regionalism, and it may realistically be expected that this "new" architecture will have many aesthetics — an architecture for each region.

The dominant aesthetic depends on climate zone and may well incorporate aspects of connection to the environment. For commercial buildings, this may mean the focus on "thick, friendly wall" architecture [5] that allows maximum thermal connection between interior and exterior. Increased energy efficiency and conservation will be a natural result of such a change.

The spectrum of old and new paradigms of architecture that will impact on the design of commercial buildings in the future are shown in Table 2.1 [6].

OLD PARADIGM	NEW PARADIGM
De-personalising	Humanising
Centralised systems	De-centralised systems
Arrogant denial of nature	Recognise our inter-dependence with nature
Narrow materialistic approach	Respect for material/spiritual connections
Indifference to consequences of actions	Acceptance of responsibility for actions
Imposed on natural world	Organic, from the natural ecosystem
Domination of short-term consumerism	Objects and systems of long-term value
Waste intensive use of resources	Elimination of concepts of waste
Polluting systems	Responsible low-emittance systems
Isolated concepts and approaches	Holistic approaches throughout
Satisfying multi-national needs	Responsive to local social needs
'International' style	Vernacular/contextural approach
Male dominated society	Male/female balanced approach
Unlimited population growth	Population stability
Restricted information dispersal	Technology/information enhancement of access
Top-down regulations	Consumer driven quality standards
Physical/economic values	Human/health values
Large-scale design	Human-scale design
Uniform, conventional, predictable	Unpredictable, surprising
Unrelated to vernacular	Vernacular
Speculative developments	Community or self-built projects for local social needs
Design dominated by visual aesthetics	Design balancing all sensory needs
Hard edges and straight lines	Curves and soft edges
High-energy systems	Low-energy materials, durable, conservable and recyclable

Table 2.1: Old and new paradigms of architecture

There was a time when buildings were built more or less in accordance with the "new" paradigm. This time ended last century for most localities and was triggered by the availability of relatively cheap energy. The task is not to turn the clock back, but rather to blend the best of the old and the new. This can be seen by considering the four stages in the development of energy efficient buildings:

- *First Generation* — those parts of the built environment that respond to historically well-defined and tested requirements and methods. The various examples of vernacular building, which draw on indigenous materials, forms and construction systems, exemplify this generation. Out of necessity, and through generations of trial and error, systems evolved that were entirely "appropriate" to the particular environment.

- *Second Generation* — those commercial buildings designed in the late 1970s as a response to the first and second "energy crises". These buildings tended to be rather extreme and relatively high tech. While they may, in some cases, have been relatively energy efficient in use, the energy demanded in the production and maintenance of these systems was extreme. In addition, the other aspects of an environment-friendly infrastructure were often ignored. Typically, this generation included atria and concentrated on natural daylighting and ventilation, together with reduced heating and cooling loads.

- *Third Generation* — those buildings that without modification to form or exterior skin treatment achieved energy efficiency through good management and the use of energy efficient equipment. This generation was all about energy efficient plant rather than energy efficient buildings and exhibited all the attributes of a high-tech society paying only passing consideration to the demands of sustainability.

- *Fourth Generation* — these examples are coming off the drawing boards at present, often as a response to global warming concerns. They are invariably low-tech solutions, that involve considerable modification to the form of the building and use non-toxic materials and other environmentally-friendly responses. They constitute what is becoming known as green, environmentally-connected architecture.

Efficient lighting typifies third generation buildings [9]. This technology and other efficient plant is adopted in fourth generation buildings, but the primary objective is an inherently efficient building shell.

With fourth generation buildings, energy reductions (or, more importantly, CO_2 emission reductions) of 70% are common [8]. Typically, these designs involve such considerations as were shown in the first generation examples — daylighting, natural ventilation, passive heating and cooling, as appropriate — along with all the lessons from the second and third generation examples. The form and envelope of the building are modified to produce a building that provides a filter between the interior and the exterior. These buildings are environmentally friendly, low impact and, probably, sustainable [10].

2.5 Thermal Differences

Design problems posed by the desire to produce energy efficient commercial buildings are complex and difficult to quantify because of inherent thermal differences. While energy efficient design criteria are easy to comprehend in residential buildings, commercial buildings offer a more variable set of criteria. The "rules of thumb" for residential building design involving orientation, glass, mass and insulation cannot be replicated for commercial buildings. Office buildings tend to be internal load-dominated in the more temperate regions (i.e. the thermal impact of the internal activities — people, artificial lighting and equipment — tends to outweigh that attributable to the external conditions). For much of the occupied time, space cooling is normally the key concern, with periods of heating required only for a few early-morning hours in winter.

Recent past logic has been to reduce the impact of the external environment to the absolute minimum by treating the external skin as a barrier as illustrated by third generation buildings. Heating, cooling and lighting has been dealt with by adding "energy services" to the building.

The elemental energy loads of office buildings are interdependent and, therefore, more complex than for residential or other commercial building types. For instance:

- artificial lighting creates heat that affects space heating and cooling loads; and

- shading can affect lighting, cooling and heating load simultaneously.

The decision to provide a simple design element, such as shading, has a difficult-to-determine impact on energy use, given a particular climate zone and building use. Intuitive analysis is always dangerous and should have an analytical back up.

Similar complexities arise in terms of a "simple" architectural decision involved in the design of new or retrofitted commercial buildings, such as the desirable glazing ratio. Recent analysis of existing temperate climate buildings [11], assuming optimum orientation [12], minimal shading, clear glass and single glazing, indicates a range of non-linear relationships, as shown in Figure 2.1.

Changing the building use characteristics and/or the climate conditions will modify the exact form of the energy relationships. Increasing glazing ratios lowers lighting needs and initially lowers heating requirements as well due to solar gain. At high ratios, overheating occurs at times (hence more cooling is needed), while more heating may be needed at other times due to window heat loss.

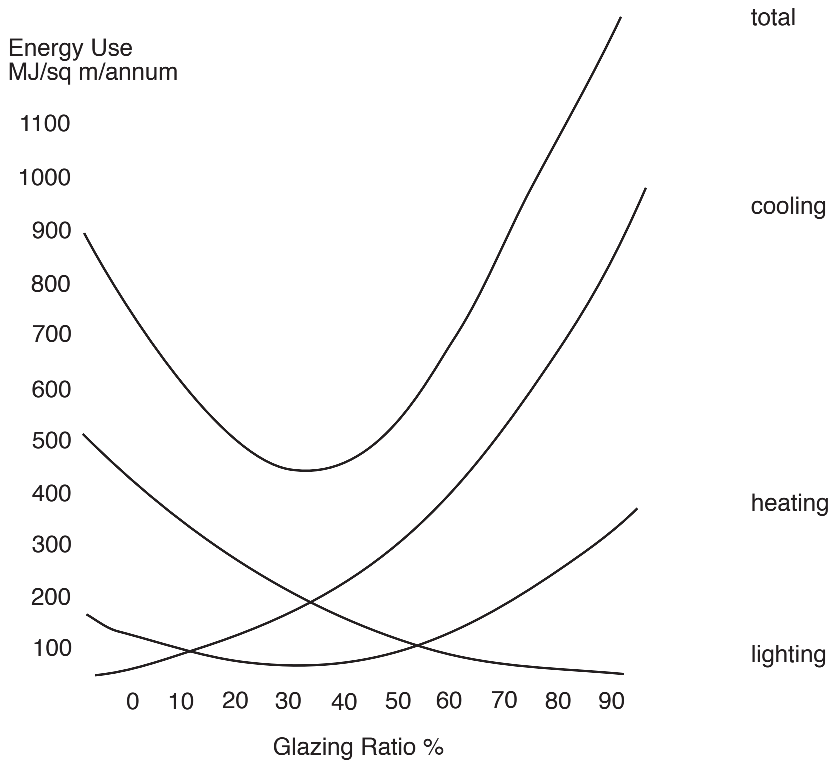


Figure 2.1: Cooling, heating and lighting loads as a function of glazing ratio

2.6 Building Models

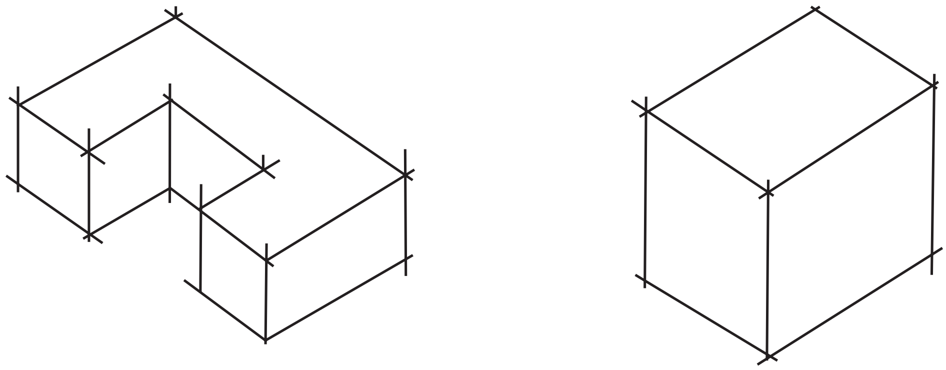
In the design of commercial buildings, there are two simple models available that can be used as basic determinants for energy efficient commercial building design [13]. They are:

- climate-adapting buildings — where the purpose is to use the climate to advantage to serve the needs of the building occupants. The positive and negative climatic influences are selectively filtered and balanced at the building's boundary to provide internal environment control (see Figure 2.2).
- climate-rejecting buildings — where the purpose is to insulate the building from the environment with the form and envelope serving solely as barriers between the exterior and the artificially conditioned interior space (see Figure 2.2).

Climate-adapting buildings provide a more interesting and stimulating internal environment with potentially lower energy costs than the climate-rejecting type. Typical climate-adapting commercial buildings, depending on climate zone and actual usage [14], tend toward:

- an increased perimeter area and good orientation;
- a thick "friendly" wall — the envelope is a filter rather than a barrier, leading to possible recesses and sky-courts;
- efficient daylighting and more efficient artificial lighting systems;
- efficient solar radiation control — glare, overheating, passive heating;
- natural ventilation and the provision of as much individual control for the users of the building as is possible;

- a clear zoning of different activities;
- a consideration of thermal mass and insulation, although these are less desirable when the climate is less extreme, even inadvisable when the internal loads are particularly significant. As the thermal conditions external to the building dominate over the internal loads, insulation becomes more necessary;
- reduced energy consumption and the reduction of CO_2 release in the construction, use and reuse/demolition stages of the building's life;
- avoidance of the use of CFC containing products, toxic materials and preservatives;
- a consideration to designing for long life and designing for many reuses of building materials and components; and
- reducing the reliance on high-tech solutions generally.



Climate Adapting **Climate Rejecting**

Figure 2.2: Climate-adapting and climate-rejecting building models

Climate-adapting commercial buildings using lightwells were built last century, as mechanical cooling or humidity control systems were not yet available and incandescent lights had only just been introduced. The U-shaped plan form was often selected for maximum connection to the external environment, with optimum natural ventilation and illumination. Openable windows, awnings and blinds were utilised to control the natural environment. Often, all corridors, stairs and lifts were located in the central area where access to natural light and ventilation was limited. Typically, floor-to-floor heights of 3.9 metres, or more, and associated high ceilings allowed better circulation of air and deeper penetration of natural light. Thick masonry walls were often used. These provide a thermal mass to dampen temperature fluctuations at different times of day, or to deliberately create temperature gradients to drive "natural" ventilation. A cube-shaped building would have been more efficient to heat (if that is an appropriate need), but difficult to cool and light naturally.

In every city of the world, there are good examples of climate-rejecting buildings. Typically, they are internal-gain-dominated, with light, air temperature, humidity and ventilation control provided mechanically. The new technologies of temperature and humidity control (developed during the 1920s) and the fluorescent light (commercially available in the 1930s) represent design solutions based on low-cost energy. Buildings such as the curtain-walled glass towers of the modernist era are typical of the climate-rejecting type. The trademark of the climate-rejecting building type is a compact plan form with a thin, tight external skin where the impact of the external environment is reduced to a minimum.

2.7 Energy Use Profiles

To obtain a meaningful method of assessing building energy efficiency, numerical targets for energy consumption need to be established. These will vary according to changing use and climate zone as the building moves from internal load to envelope domination. The methods adopted worldwide typically relate the amount of energy consumed for a given floor area for a given time. Megajoules per square metre per annum is the typical set of units used. For some specialist uses, such as hotels, it is common to assess energy consumed in terms of the energy use per occupant per unit of time. In all cases, the overall target is the sum of the energy-using components common to that particular building type. Targets have particular relevance for regulatory authorities (in the production of performance-based building codes) and for designers (in comparing one design solution with another and assessing the overall impact on the energy use profile of the eventual building).

Energy targets are inherently crude in terms of their impact on greenhouse gas considerations in that the source of the energy supply is not normally considered and, therefore, the overall greenhouse gas emission impact is not open to inspection. Clean energy from renewable sources may well be a sustainable system of energy use, but this fact is not usually considered. In addition, the total life cycle energy use of the building is not normally a consideration. As well as the energy used in the normal day-to-day life of a building, the energy required to produce the building materials and components (often referred to as the "embodied energy") is an important factor, as is the energy component of the demolition or reuse stage.

As environmental concerns become more dominant, all buildings will increasingly be seen as a resource to be conserved and modified to produce a new use. Building components will increasingly be designed and manufactured to allow for this reuse. Of importance in terms of possible climate change impacts, is the greenhouse gas emission component of the particular system involved in either a new or retrofit situation. Even fully-renewable forms of energy supply may not produce particularly sustainable results under this form of investigation [15].

A review of a variety of energy targets, as presented by a range of authorities worldwide, produces some interesting comparisons that tend to emphasise the inherent difficulties involved in such methods.

- The precise definition of exactly which element should be included is a real problem. Is energy use related to the building owner and/or the tenant?
- Will the total energy use for all the electronic equipment in the building (including computers and catering equipment) be considered?
- Are net rentable areas or gross floor areas of buildings important, regardless of the area served by each element?
- What period of operation should be considered — does "annual" really mean, say, 2500 operating hours per annum?
- What are the precise use characteristics to be incorporated in the proposed building? The rather crude breakdown into "office", "retail" etc. is unlikely to be precise enough.
- Minor changes in climate have been shown to produce major changes in the energy use profile of a particular building type. Annual degree-day analysis may not be accurate enough for some building types, where a more precise diurnal climate definition may be required.
- What are the operating characteristics of the building user? An occupier with sophisticated energy management systems firmly established as company policy will out-perform a less aware occupier.
- Upwards of 25% variation may well be attributable to management factors.

Considerable care is needed to provide real indicators for possible energy efficient solutions to commercial building design in the future. Further information on building code approaches to energy efficiency is presented in Chapter 8, "Barriers, Codes and Standards".

2.8 Worker Efficiency

Clearly, for many commercial businesses, potential savings in the "personnel costs" area are of critical importance, and are likely to outweigh those possible in the "energy" area. If better performance can be achieved from individual workers in the retrofitted worker-efficient (and usually energy efficient) building, then the “personnel costs” area can be reduced proportionately. Productivity is a broad concept that includes not only employee work performance, but also the associated organisational costs, such as employee turnover, absenteeism, tardiness, required overtime, vandalism, grievances and mental and physical health. Historically, much of the research on productivity has relied on measures of employee satisfaction as indicators of productivity [16, 17].

A recent Auckland study [18] involving more than 1500 workers in airconditioned offices suggests a similarly high level of dissatisfaction with the quality of the office environment, with clear contradictions arising on aspects of temperature, ventilation and lighting, as shown in Table 2.2. The clear conclusion, because of the high level of dissatisfaction and contradiction, is that office staff desire to control their own environments more than present airconditioned offices allow. Of course, negotiation and compromise between workers may be needed where several people occupy the same work space, but at least the point of control is closer to the “consumers”.

The typical environmentally-connected commercial building with “thick” wall characteristics admirably satisfies this desire for more natural environments with better individual control.

The worker efficiency argument is attractive, as even a slight improvement in productivity will have a significant impact on the overall economic structure of the organisation.

Ambient Condition	Comment	Percentage Agreement
Temperature	Too cold	31
	Too hot	48
Ventilation	Too stuffy	57
	Too draughty	22
	Don't know	21
Lighting	Too bright	34
	Wrong angle	25
	Too glarey	37
	Too dark	28

Table 2.2: Results of worker survey in airconditioned offices

2.9 Actions

Considerable skill and compromise are required for the design of new commercial buildings and for the retrofit of existing commercial buildings to produce solutions that satisfy the requirements discussed earlier — the conservation of nonrenewable resources, carbon dioxide emission reductions and the production of worker-efficient, non-toxic interiors. To defend such solutions in the face of short-term economic considerations may be even more demanding. However, the benefits are significant in terms of individual, national and even global benefits.

When designers try to bring full building life-cycle, not just day-to-day operational, carbon dioxide emissions into consideration, they face information and analytical problems. The available tools and data are often subjective or contradictory.

The challenge, at present, is for the producers of the built environment (including those involved in retrofit) to make sense of the information becoming available and interpret this often conflicting data for each project. Meanwhile, as further research is carried out worldwide, the most basic actions within the designer’s influence include [19]:

- minimising energy consumption to reduce CO_2 release;
- avoiding the use of CFC containing products;

- designing for long life; and
- designing for many reuses of building materials and components.

In terms of energy efficiency, the two main variables of building use and climate zone must be considered with the architectural possibilities, including form, external skin, mass, glazing, ventilation, insulation and worker efficiency. These are discussed below.

- *Form* — the modification of the overall form of the building to increase it's total surface area, when uses are tending toward internal load dominated (see Figure 2.3). Strategies include the use of lightwells, changing building plans to a rectangular shape and using atria.

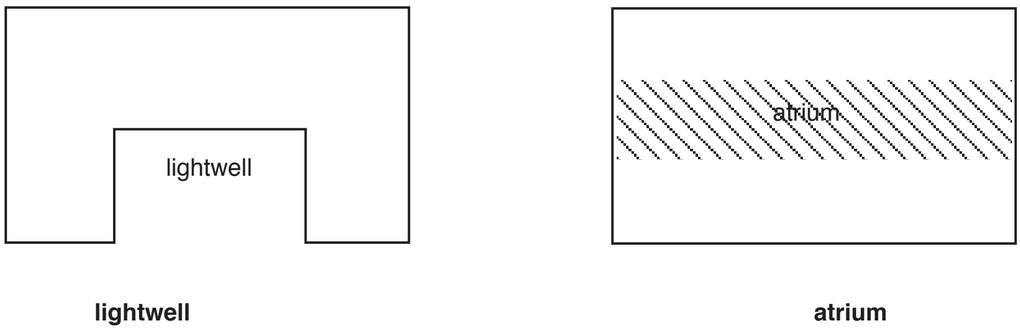


Figure 2.3: Climate-adapting form strategies

- *External skin* — the modification of the nature of the surface to the building to provide a filter, rather than a barrier, for office-type uses in extreme climate zones (see Figure 2.4). Typically, the retrofitted wall will be thicker than those walls associated with mechanically-modified internal environments.

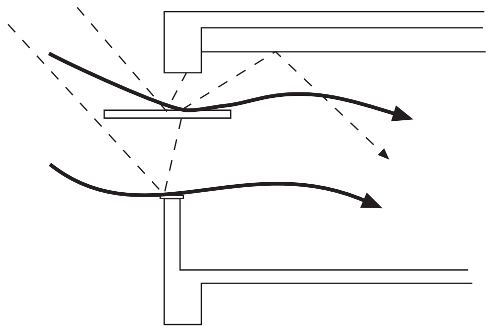


Figure 2.4: Filter skin — air and light permeable

- *Mass* — the inclusion of extra thermal mass in situations that demand thermal extremes to be equalised as much as possible, or to create natural ventilation (see Figure 2.5).

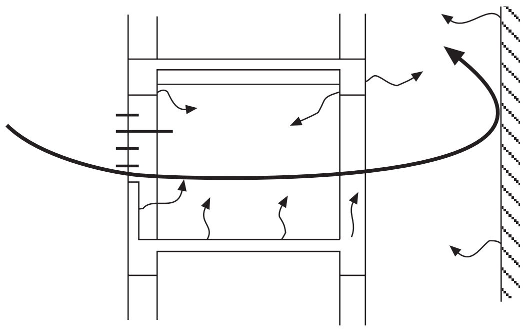


Figure 2.5: Thermal mass/air shafts for passive ventilation

- *Glazing* — while fenestration considerations should never outweigh the very real advantages of good visual connections between inside and outside, window size and type become important in terms of available solar radiation, daylight, heat loss and the possibility to require the complete shading of the walls in very hot climates (see Figure 2.6).

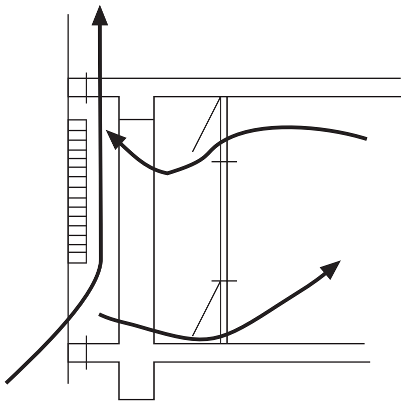


Figure 2.6: Recessed windows/passive ventilation

- *Ventilation* — when the building occupants are generating considerable extra heat, ventilation by natural means can be a critical concern, even in temperate climates. Possibilities range from producing an internal environment with adequate air quality (the minimum standard) through to more sophisticated night flushing or humidity modification.

- *Insulation* — the desirability of thermal insulation in the external skin of the building is obviously lower when the climate is less extreme, even inadvisable when the internal loads are particularly significant. As the thermal conditions external to the building dominate over the internal loads, insulation becomes more necessary.

- *Worker efficiency* — in this area, the gains are extremely difficult to quantify except in the well-known instances of proven toxicity or airborne disease. The main actions include:

  — using less-toxic materials and preservatives;

  — ensuring adequate indoor air quality;

  — producing quality natural environments;

  — reducing the reliance on high-tech solutions; and

  — providing as much individual control for the users of the building as possible.

To achieve an element of "sustainability" and, therefore, "energy efficiency", the climate-adapting type of office building described in Section 2.6 is necessary.

2.10 Conclusions

A new architecture of office buildings is likely to evolve [20]. The sustainable urban forms of the future will have to be derived from existing buildings and urban systems, but they may well be significantly different from those of the past in their form and long-term operating characteristics [21]. In this, the technologically-developed countries and the less-developed countries both face the need for major transformations [22]. Neither has developed built-environment systems that are friendly to both people and the environment. The problem facing all humanity, rich and poor alike, is to devise new and sustainable alternatives.

Everyone has a vested interest in the total success of this venture because the consequences of failure will accrue to all. The considerate design and retrofit of commercial buildings must be a vital part of any sustainable future. The development of a new "aesthetic" is exciting and demanding and offers real opportunities for architects, and others in the industry, worldwide. There are significant opportunities for research and development in temperate-climate countries such as New Zealand. Inherent skills can be used to impact far wider than just within the narrow confines of the building industry.

End Notes

This chapter is very much a "summary" type of document and draws heavily on many of the original papers referenced below.

1. This notion is part of the "judgement" section of the Intergovernmental Panel on Climate Change Report 1990.

2. The UN Conference on Environment and Development, Brazil, June 1992, provided a base for action. The UIA (International Union of Architects) Project Group "The Implications for Architecture and the Built Environment of the Greenhouse Effect" presented the built environment arguments for achieving sustainability.

3. See Rodger, A (1990)." Towards Sustainable Systems of Settlement: Physical Forms and Social Organisation", *Fundamental Questions Paper No 11*, CRES, Canberra. Also Rodger, A (1991). "Urban Consolidation in the Context of Sustainable Development", *Conference Proceedings, Urban Consolidation: Myths and Realities*, Australian Institute of Urban Studies, Belmont, Western Australia.

4. Agenda 21, signed in Rio de Janeiro in June, is a morally binding guideline for governments and demands a very clear set of actions from those involved in the production and use of buildings generally. See the paper "After UNCED, Sustainable Built Environments" in the *Proceedings of the Passive Low Energy Architecture Conference*, Auckland University, August 1992.

5. See Robertson, G (1991). "Thick friendly walls — energy efficient commercial building design", *Proceedings ISES 1991 World Solar Conference*, Denver, Pergamon.

6 These paradigm expressions were formulated by Graeme Robertson of the University of Auckland and widely circulated by the Chair at the UIA (International Union of Architects) Congress Theme Breakout Sessions at Chicago in June 1993. As such, they were widely adopted by the architectural profession and formed a basis for the Congress "Declaration of Interdependence" taken up by the 14000 architects present.

7. See IPCC Report 1990. The building stock currently consumes 50% of all UK energy, which results in 300 million tonnes of carbon emissions per year, according to their Department of Energy. The proportions for developing countries are far less, but always significant. Even in a country such as New Zealand with relatively "clean" hydro electricity supplies, CO_2 emissions caused by the built environment are substantial. The construction (or embodied energy) component, often based on coal or oil, can become more significant as the "through-life" (or operational) component (mostly electricity) drops.

8. D S Gillingham, President of the Chartered Institution of Building Services Engineers, UK, presented an excellent plenary paper on this topic to the First World Renewable Energy Congress, Reading, 1990. Also Alan M Brown, Enersonics Pty Ltd, Hawthorne, Victoria, Australia, has widely written on his impressive energy savings as a consultant to a range of commercial premises in temperate climate conditions.

9. Webb, B (1990). "Commercial Buildings: Efficient Lighting", *Proceedings of the International Conference on Water and Energy Conservation in Commercial Buildings*, Brisbane, has shown that the energy level required to produce a nominal average illuminance level of 500 lux in commercial offices has declined from around 38 watts per square metre in 1975 to 11 watts per square metre in 1988 with even further reductions likely.

10. While developed countries may eventually reduce CO_2 emissions by up to 50%, the pessimistic view is that this will not be sufficient to produce a sustainable environment. In addition, increases in third world emissions will demand a more dramatic response from the developed world that will involve significant modification to the pattern of cities. The fifth generation energy efficient building will entail decentralised, low-scale developments that require less movement of goods and people. These are beyond the scope of this report.

11. As yet unpublished study of 150 Auckland office buildings constructed in the period 1984-89, by Graeme Robertson of the University of Auckland

12. Dominant north-facing long walls with a strong connection between interior and external spaces and skin design to allow maximum daylight intrusion but also maximum solar radiation control.

13. The two model distinction is a relatively simplistic view, but is useful if only to highlight the differences. In addition, architects respond well to the notion of 'models' to describe basic design possibilities.

14. An increased internal load makes the listed tendencies more generally applicable.

15. Carbon dioxide emissions are often created even with renewable energy forms and are usually ignored. For example, producing a unit of biomass energy, such as methanol, can create substantial fossil fuel emissions. [Editor's note: See Part 3, "Transport", Chapter 4, "Alternative Fuels".]

16. See Wineman, J D (1986). "The importance of office design to organisational effectiveness and productivity", in *Behavioural Issues in Office Design*, Van Nostrand Reinhold, New York, 1986.

17. See Hedge, A (1986). "The impact of design on employee reactions to their offices", *Behavioural Issues in Office Design*, Van Nostrand Reinhold, New York, 1986.

18. This study is reported in "Energy efficient commercial buildings — a realistic market objective", *Architectural Science Review*, 34.4. December 1991, Sydney.

19. See Rodger, A and Robertson, G (1991). "Victims, villains and white knights", *Proceedings Australia New Zealand Solar Energy Society Conference*, Vol. 1, Adelaide.

20. See Robertson, G (1990). "The marketing of energy efficient multi-storey commercial building design", *Proceedings CIB W70 Management and Maintenance of Buildings Conference*, Singapore.

21. See Pearman, G (1991). "Climate change: a factor in building design", *Proceedings CIBSE Conference*, Sydney, Australia.

22. See Yeung, K (1991). "Designing the tropical skyscraper", Mimar Architecture in Development, no 42.

Chapter 3
Commercial Lighting

3.1 Introduction

The main objective of this chapter is to demonstrate to building owners and managers, landlords and tenants, designers and builders, that the techniques for saving energy through lighting are relatively simple, well-proven, beneficial and save money. Savings can, on the whole, be accurately calculated in advance and require neither "guestimates" nor expensive and time-consuming computer modelling and monitoring.

Even buildings that have only just been completed can be improved. They were very likely designed at a time when the techniques now being applied so successfully were only beginning to appear on the market, and were subject to doubts, disbelief and too little promotion.

It must be emphasised that this chapter is concerned only with techniques for reducing lighting energy consumption that are:

- cost effective — simple payback periods of less than three years are commonplace, but measures that have payback periods of up to five years or even more should be acceptable, especially where life-cycle costing of building projects is under consideration; and
- user-friendly — in other words, do not entail a worsening of the existing or planned working environment. It will, in fact, be shown that there may well be positive side-effects in the form of better light quality, reduced maintenance costs, improved staff comfort and health and even higher lighting levels.

This chapter should be read in conjunction with Chapter 13 "Opportunities in Domestic Lighting" in Part 1 "Domestic Buildings". Domestic-scale lighting has a place in commercial buildings, especially shops, workshops, small offices, etc. The two chapters are also complimentary in their treatment of technical issues.

3.2 The Potential for Energy Saving

A study carried out by Victoria University in Wellington and published in 1986 (Baird and Newsam, 1986) showed that lighting accounts for about 30% of the electricity used in commercial and institutional buildings. More recent studies in the UK and the USA have come out with higher figures, and it may well be that in present-day New Zealand the figure is closer to 35%, or even higher where there is no electrically-driven cooling plant. It follows that if lighting energy usage in this sector can be cut by 50% (which is quite reasonable, as this chapter will attempt to prove) the overall electricity consumption in the average building will be reduced by at least 15%.

This may not sound like very much, but it should be borne in mind that by far the greater part of this energy saving will be during daytime hours — in other words, at prime cost both to the consumer and to the supply authority. Daytime electricity usage determines the total generating capacity needs for the nation.

The effect of lighting energy savings on airconditioning costs is a factor that is often overlooked. In the summer months, every ten kilowatts of power consumed by the light fittings in an airconditioned building require about three kilowatts of chiller power to take it out again. Allowing for seasonal variations, it is reasonable to allow an additional 15% to 20% for airconditioning energy savings on top of any lighting system energy savings. Even in the winter heating season, there will still be a saving on overall energy cost, even though additional direct space heating may be needed to compensate for the loss of heat from lights. This is because lighting is an expensive space heating option compared with, say, natural gas. Furthermore, using a fuel like natural gas directly for heat is more energy efficient than using it to generate electricity for resistance heating.

The combined effects of higher efficiency light fittings, control systems and more effective use of daylight can produce energy savings of over 100% when airconditioning savings are credited to the lighting account.

3.3 Old Buildings: New Buildings

Cost/benefit analyses work out quite differently according to whether one is considering:

- the retrofitting of existing lighting installations, where nothing else is changed; or
- the construction of new lighting installations.

The latter category includes both new buildings and refurbishment projects.

The retrofit category includes most of the projects that are initiated as a result of energy audits. It is usually necessary to convince the owner, or the tenant, that it will pay them to modify the existing installation as recommended in the audit report. Thus, all the costs involved in the modifications, including those of the contractor, must be included in the capital cost calculation.

However, the calculated payback period for many retrofit projects can be considerably reduced if one looks at the life expectancy of the existing light fittings and the ongoing, and probably rising, cost of maintenance. The retrofit can reduce maintenance costs by using long-life light sources. A more complex calculation involving discounted cash flow may be more appropriate than simple payback estimates (refer to Chapter 15 "Economics of Domestic Energy Efficiency" in Part 1 "Domestic Buildings").

Energy efficient lighting in new construction can be much more cost-effective than in retrofit projects. This is because the cost/benefit study need not consider the whole of the cost of the energy efficiency scheme, but only its marginal cost over the original scheme (probably "lowest-first-cost").

New projects are highly appropriate for energy efficiency measures. The marginal cost may even turn out negative. Energy efficient design in the new project situation may also enable savings to be made in the size, and cost, of the building's electrical distribution system. All the client pays for is the extra design work and the cost comparison exercise. Savings commence as soon as the premises are occupied and the payback period on the additional investment is negligible.

3.4 Light Sources

Daylighting

Direct daylighting using windows can pose a problem of heat gain and glare. Careful recessing of windows back from the perimeter wall and other architectural details together with the use of special glazing surface treatments can manage this problem. Aside from windows, new architectural daylighting devices are currently in development and demonstration by various manufacturers (California Energy Commission, 1993). These devices work passively or actively to collect sunlight and transport it into a building to displace artificial light sources.

Holographic glazings work by redirecting incident light towards the ceiling in the interior of the space from which the light is diffused. These glazings, which double as conventional windows, have an extremely thin, transparent holographic pattern fabricated into the glass.

Light pipes transmit light through a pipe with a series of mirrors or reflectors to diffuser units. Prismatic light guides are hollow structures wherein light is transmitted by internal reflectors and distributed along the surface of the guide. Reflective mirror guide systems work with a series of specular reflectors on inner surface walls. They do not need dedicated tubes (hence offer flexibility) and can be designed to distribute light through diffuse reflection. Lens guide systems operate with a series of lenses transmitting light from one lens to another further inside the space.

Light pipes and holographic daylighting systems have the most promise for cost effective application in the near term. Other daylighting devices that have been suggested, such as fibre optic light transmission and directional tracking skylights, are unlikely to become cost effective for the foreseeable future due to high costs.

Fluorescent Tubes

Fluorescent tubes of the 600 mm, 1200 mm and 1500 mm (2 foot, 4 foot and 5 foot) variety have been in common use for the past 50 years. Lamps of this type are eminently suited to the needs of commercial and many industrial interiors. This is mainly because their dimensions and light output enable them to be made up into luminaires of the right shape and size for the situations concerned, while at the same time ensuring that glare can be kept within acceptable limits.

There have been steady improvements in lamp efficiency and price over the years. It is interesting to note that the price of 38 mm (“fat“) tubes is going up and that of 26 mm (“thin”) tubes, especially triphosphor types (see below), is going down. This is an excellent trend from the point of view of the economics of energy saving.

For several years now, 26 mm tubes have been supplied as standard with all new luminaires delivered to site in New Zealand. This raises the question of why so many luminaires are still using the old 38 mm tubes. It should be well known by now that 26 mm tubes are cheaper to buy, cheaper to run and save energy.

It is, in fact, highly advantageous to make a change from 38 mm to 26 mm tubes wherever this is technically feasible without costly modifications to the fittings. A simple calculation will show that it is economic to throw away existing 38 mm tubes (even if they are new) and replace them with 26 mm tubes. Assuming normal prices for electricity and average hours of use, the simple payback period is usually less than two years. Energy savings from this simple measure range from 7% for 600 mm tubes to 9% for 1500 mm tubes.

A problem arises (on a steadily diminishing scale) from the fact that the 26 mm tubes will not work with resonant-start or instant-start control gear of the type that was previously popular. This is because these starting systems will not provide the extra high voltage (about 800 volts) needed to “kick-start” the discharge in the Krypton-filled 26 mm tubes. The older 38 mm tubes are filled with argon and only need about 400 volts. In such cases, asking for the energy savings to pay for the cost of a complete upgrading of existing light fittings from 38 mm to 26 mm, including new switch-start control gear, may seem somewhat optimistic. However, it can be feasible if other modifications are carried out at the same time, such as installing high efficiency control gear, reflectors or some form of external control system. These will be discussed in more detail later in this chapter.

Triphosphor Tubes

Triphosphor tubes have similar dimensions and power ratings to the “regular” 26 mm tubes but use three main phosphors, like the red, green and blue phosphors of a television screen. The result is a better quality of light, which is excellent for colour rendering. In addition, the light output is about 15% more than for regular 26 mm tubes.

The price of triphosphor tubes is higher than for ordinary tubes, but is showing signs of coming down due to a steadily increasing demand. When the extra light output can be utilised to make up for any loss imposed by other changes, the overall cost effectiveness can be highly attractive. The use of triphosphor tubes should always be considered as part of any energy-saving lighting scheme.

For example, some years ago a carpet factory was using fluorescent tubes of good colour-rendering quality but low efficiency. A change to triphosphor tubes was recommended, which enabled the removal of half the fittings. The measure cost $9000, but saved the factory $23,000 a year.

Good colour rendering is essential for many activities and this can be achieved in an energy efficient manner. As a result of technical advice to the Department of Health in 1987, triphosphor tubes have been accepted for use in clinical examination areas of hospitals, including operating theatres. Their introduction has enabled the low-efficiency tubes previously used to be discarded, and energy savings of up to 70% have been achieved.

High Efficiency Control Gear

Control gear, in this context, means the total package of starter, choke or other form of ballast, and, where fitted, a power factor correction (PFC) capacitor. These devices perform essential functions within the light fitting, the explanation of which is outside the scope of this chapter. The alternatives that are now available range from a set of individual starters, ballasts and capacitors to electronic ballasts that perform all control functions.

The basic type of ballast, as used in "regular" switch-start circuitry, wastes energy due to its ohmic resistance. In the case of a 1200 mm tube circuit, this loss is of the order of nine or ten watts. However, ballasts are now available, notably from ATCo of Auckland, that are designed and built for loss figures of the order of five or even three watts in this application. They are more expensive, of course, and it is necessary to carry out cost-benefit analyses to determine their cost effectiveness as energy savers.

An even newer low-loss ballast, the "Gold Label" from RTC of the USA, marketed by Exicom Energy NZ Ltd of Auckland, comes in a package that includes componentry designed to not only soft start and run the tube, but also to correct the power factor almost to unity. Thus, it takes the place of the plug-in starter and the PFC capacitor, as well as the ballast. The energy saving is claimed to be up to 30%, similar to an electronic ballast, but there is some loss of light output from the tube. This can be avoided if a new type of triphosphor tube from NEC, also marketed by Exicom Energy, is used. This tube has a life expectancy of 15,000 hours, almost twice the usual figure, and is guaranteed for 12,000 hours.

Electronic ballasts work by first rectifying the mains power and then converting the DC to high frequency AC before applying it to the tube via a small air-cored choke. Higher efficiency results from this high frequency operation and the lower tube temperature. In addition, the energy losses in the ballast are reduced. There is little or no loss of light output — in fact, some makers claim an increase.

Broadly speaking, the "watts loss" in the ballast is reduced to a much smaller figure than can be achieved at mains frequency, while the power consumed by the tube (to produce roughly the same light output) is reduced by around 12% to 15%. For example, the total power input to a 1200 mm tube circuit goes down from 46 watts to about 34 or even 32 watts, for an overall saving of 30%.

Electronic ballasts are currently expensive, especially where single-tube fittings are concerned. However, they can often be justified on economic grounds in situations involving long hours of use, or where automatic dimming to save energy is involved in the control system. They are the only practical option where dimming is an operational requirement.

It should be remembered that there is not only an increase in efficacy (which means efficiency in lumens per watt) when electronic control gear is used, but there is also an increase in lamp life, due to softer starting and cooler running (with all types of low-loss ballast, ballast life is lengthened due to lower operating temperatures). These factors should be taken into account when analysing cost benefits.

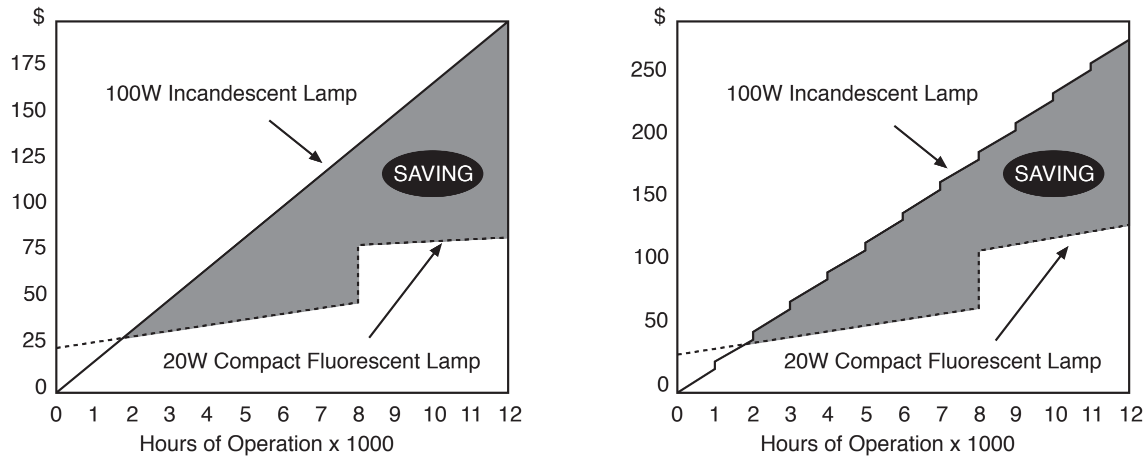
In retrofit situations, replacement of obsolete resonant-start or instant-start control gear with electronic gear may be an attractive option that shows economic advantages over the alternative of ordinary switch-start gear. The comparison is between supplying and fitting (for a pair of lamps) two switch-start ballasts, probably a new power factor correction capacitor and two plug-in starters that must be accessible, or just one twin-tube electronic ballast that performs all these functions.

There is an economic compromise available between the low capital cost of regular switch-start gear and the high capital cost, but better efficiency, of high frequency electronics. New electronic starters have been developed. While these still need ballasts and PFC capacitors, they are much better than the old electronic starters in that they include soft starting and tube failure protection, leading to longer tube life and the elimination of tube end blackening. Obviously, this is an appropriate course of action where access to the fittings is difficult and maintenance expensive. It should be noted that electronic starters do not save operating energy (they save energy embodied in the tube manufacture through longer tube life).

Compact Fluorescent Lamps

To a large degree, compact fluorescent lamps have already been accepted in commercial buildings. Earlier objections on grounds of "harsh" colour and incompatibility with the warmth of the incandescent bulb, have now been removed — compacts with a colour temperature of 2700 K can be ordered, which makes their light almost indistinguishable from incandescent lamps.

At present they are expensive and cost several times as much as their "big brothers". However, with 75% to 80% energy savings compared to incandescent globes, they pay for themselves in a short space of time in most commercial and industrial situations. If the hours of illumination are short, say less than 3000 per year, the payback period may be lengthy.



(a) 20 W compact fluorescent vs 100 W incandescent — no labour costs

(b) 20 W compact fluorescent vs 100 W incandescent — plus labour costs

Figure 3.1: Comparison between compact fluorescent lamps and incandescent lamps

Against that, there are signs that the price will fall as demand grows. Once the price of compact fluorescent lamps falls to eight times that of an incandescent bulb — and some of them have almost reached that point now — the battle is won, because they last eight times as long and the savings in the maintenance cost of changing bulbs will compensate for the cost of finance needed to serve the higher capital costs. This is shown in the second graph in Figure 3.1. When labour costs are counted, the full cost of an incandescent bulb rises from $75 at 5000 hours to around $100. The full cost of CFLs at 5000 hours does not increase from the non-labour cost of $30. By 12,000 hours, labour charges and the cost of a new bulb increase the total costs of CFLs from about $80 to $125. The increase for standard lamps is greater, from around $200 to $260.

Control Gear for Compacts

As with the bigger tubes, compact fluorescent lamps require control gear or ballast/starter combinations, in order to operate. Again, there is a choice between "regular" ballasts plus starters, or electronic ballasts that perform both functions.

As for fluorescent tubes, regular ballasts for compacts are cheaper, but consume more power than their electronic counterparts, as shown in Figure 3.2. The lamps are made by Philips, but other suppliers offer similar ratings. It is interesting to note that, when choosing a substitute for a 75 watt bulb, the electronic PLCE15 has no energy saving advantage over the equivalent, and cheaper, combination of PL11 lamp and regular ballast. Electronic ballasts can be supplied "built-in" with the lamp or in a very compact and lightweight adaptor. Compact fluorescents with electronic ballasts are rapidly gaining favour over those with regular ballasts. Furthermore, those with separate adaptors are becoming popular because the ballast is often good for two or more tube lives.

There are some lingering problems with compact fluorescent lamps in the more technical areas of power factor and harmonics. Power factor correction (PFC) at source, i.e. at the luminaire, has been standard practice for a long time in the case of "regular" fluorescent tubes. Compact lamps, however, are often supplied without PFC because of space — and price — restrictions. Small numbers of such luminaires do not give too much trouble, but PFC is essential to avoid excessive circuit current where large numbers are involved.

Another problem arises from excessive harmonic generation from some types of compact fluorescent lamps. Again, it is only troublesome where compacts represent the major light source in a given building. The problem is being tackled at international level and the industry is now responding by producing products that comply with the requirements of the power supply authorities. Further information on this issue is provided in Part 1 "Domestic Buildings", Chapter 13 "Opportunities in Domestic Lighting", Attachment 2.

A device that satisfies the most critical specifications for power factor and for harmonics suppression is the "Smart Lamp", an electronic ballast for compact fluorescent lamps in the form of an adaptor made by Electronic Ballasts Pty Ltd of Bayswater, Victoria. It can be obtained from suppliers in New Zealand.

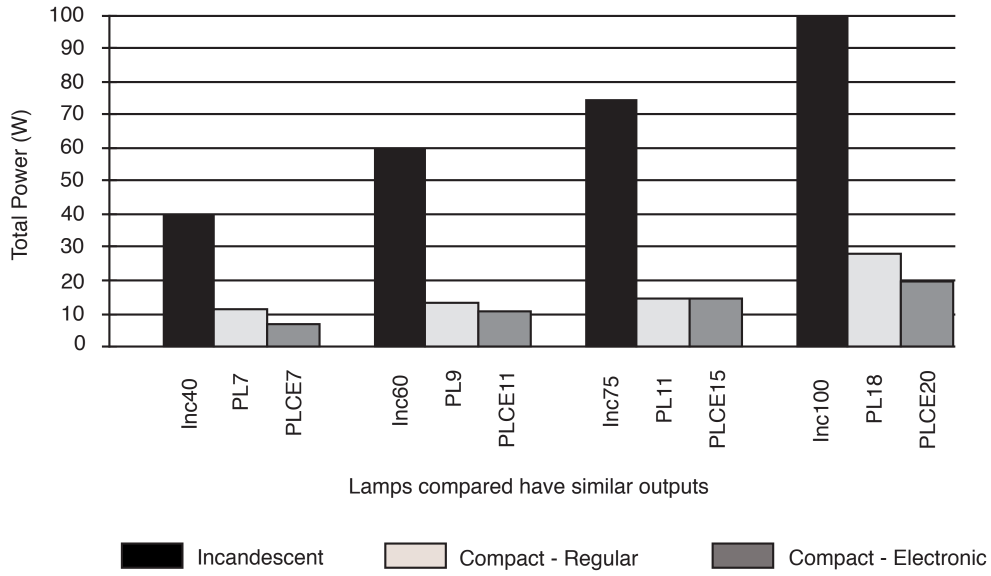


Figure 3.2: Power requirements for lamps with regular and electronic ballasts

High Intensity Discharge (HID) Lamps

Recent developments have shown steady and significant improvements in the lumens per watt figures for high intensity discharge lamps and fittings and improvements in their colour rendering abilities. Although the varieties available are too numerous to list here, types range from low pressure sodium lamps (SOX), which have the highest efficacies (of up to 125 lumens per watt or more), through to high pressure sodiums (SON) at up to 100 lumens per watt or so, metal halides (HPI) from 60 to 80 lumens per watt, down to mercury vapour lamps at around 40 to 60 lumens per watt.

Metal halide lamps are available in a range of outputs, from 35 W to 2000 W. The larger lamps are, of course, the most efficient and find application in industry and as uplighters in commercial buildings, especially those with high ceilings. It is because of the good colour rendering properties of these lamps that the smaller sizes have been developed mainly for use in wall-mounted fittings and aesthetic applications.

From the point of view of energy efficiency, it cannot be assumed that the most efficient light source will necessarily lead to the lowest figures for specific energy, or watts per square metre. For example, the higher efficiency of the HID lamps used in uplighting installations is negated to a large extent by the losses incurred through having to reflect the light off the ceiling and walls before it can be used.

Nevertheless, an HID uplighting installation can occasionally be made to outperform a fluorescent lighting system, especially where the latter is itself inefficient. In a Lower Hutt swimming pool complex, 24 fluorescent light fittings were replaced by six metal halide uplighters. The appearance was greatly improved, the illumination around the pool was doubled and the energy consumption halved.

Tungsten Halogen Lamps

These incandescent lamps, which come in either low voltage (generally 12 volts) or mains voltage form, have efficacies only marginally higher than "straight" incandescent lamps. Their principal virtues are their controllability, which is due to the small source of radiation and compact reflector. Properly applied, these lamps can offer energy savings when compared with their predecessors, the PAR and other forms of built-in reflector lamp. Incorrectly applied, however, such as in rows and rows of downlighters, they can be wasteful.

A range of lamps from Sylvania embodies mains voltage tungsten-halogen lamps inside PAR envelopes, making them suitable for direct replacement. They offer longer life and lower power for similar light outputs.

Many of the pitfalls associated with tungsten halogen lamps are well-detailed in an IESNZ conference paper (Waller, 1989).

3.5 Luminaires

The selection of a light source is inseparable from the selection of a luminaire — bare bulbs are rarely acceptable in today's environments. Obviously, once a lamp of any kind is put inside a "box" or light fitting of any kind, there will be a loss of useful light output due to absorption of light within the box. The simplest measure of the efficiency of the unit is the total light output ratio (TLOR), which can be as low as 0.5 for low-cost fluorescent fittings, even those internally treated with high-reflectivity white coatings.

Diffusers and Controllers

In the office situation, diffusers or other forms of light controller are essential to avoid the stark appearance and glare of bare fluorescent tubes. Earlier types used opal plastics, which absorbed up to 30% or more of the light output according to the density selected. As a consequence of their PVC content, light transmittance becomes even worse with age as they develop a yellowish shade. Modern fittings use prismatic acrylics, which have higher transmittance factors and do not deteriorate so rapidly.

A simple remedy for aging diffusers is to replace them with new diffusers of acrylic type. These can be obtained made-to-measure by specialist suppliers. For example, a quotation was received from a contractor to supply and fit extra light fittings to a Wellington office in order to improve illuminance levels. Power consumption would have almost doubled if this scheme had gone ahead. However, the Energy Management Group of the Ministry of Commerce (now part of EECA) intervened before these changes were made. Instead of installing extra fittings, the old diffusers were replaced with new ones and the 38 mm tubes replaced with the 26 mm type. The result was a doubling of illuminance and a saving of 7% in energy, not to mention a few thousand dollars.

"Egg crate" type grilles are available in many forms as substitutes for diffusers where ceiling reflection problems exist at VDU stations. These controllers are effective, but they concentrate the light in a downward direction, usually within a 45° "cut-off" range, giving rise to loss of uniformity of illuminance where they are retrofitted. They also absorb a lot of light. More, closer spaced fittings are the obvious way out of this problem, but this increases costs as well as energy consumption.

Uniformity is discussed later in this chapter. The basic question to consider is how essential is uniformity? Provided there is sufficient light at the workstation, a lower light level in other areas should be fine. At VDU stations, levels as low as 200 to 300 lux are actually beneficial and are recommended by most authorities, including the New Zealand Employment Service (1988).

High efficiency luminaires that employ special mirrors and louvres have been available for many years. Their high cost has been a deterrent, but lighting design using these fittings can reduce specific energy consumption in a cost effective way.

High Efficiency Reflectors

A more recent development is the high efficiency, silvered, or high-purity aluminium, reflector system (Figure 9.2 in Chapter 9 "Case Studies" compares the performance of different reflector surfaces). Maximum use is made of high specular reflectance (over 95%) by ensuring, through precise optical control, that as much light as possible from each fluorescent lamp bounces only once off any part of its reflector before leaving the luminaire. Thus, multiple reflection is eliminated and attenuation of light minimised. Extremely high efficiencies result. There are test reports from certificated laboratories showing TLORs of 0.80 and even higher. This means that one lamp can do the work formerly performed by two — or, at worst, two can do the job of three. Energy savings are, therefore, 33% to 50%.

The established lighting industry has shown signs of being reluctant to design and market a range of fittings that employ reflectors of this kind. However, things are changing and at least one manufacturer in New Zealand has taken up the challenge and is developing such a range.

Meanwhile, retrofit of existing light fittings is a proposition that is attracting more and more attention. Retrofit is not easy — each case is different from the one before. Care is necessary to ensure that an existing fitting can be modified to accept the new equipment without expensive problems, such as having to shift the control gear out of the way of the reflector or modifying the geometry of the reflector.

Generally, it can be said that the older the luminaire, the more cost effective it would be to upgrade. For example, fittings having three 1200 mm fluorescent tubes of the 38 mm kind with resonant-start ballasts are now becoming a maintenance problem of steadily increasing proportions. The 38 mm tube is hard to obtain and its price is going up. Control gear of the kind required is obsolete, so that the usual remedy is to re-equip the fittings with switch-start gear and regular 26 mm tubes. But is this the best way to go?

At the National Bank headquarters building in Wellington, over 60% of lighting energy was saved by replacing the three old ballasts and the PFC capacitor with one electronic ballast, fitting a high-efficiency reflector and providing two tubes of triphosphor type in place of three 38 mm ones. There are greatly reduced maintenance costs, no visible or invisible flicker, better colour rendering and higher light levels. The cost, compared with simply refitting with lowest cost componentry, will be recovered in just over three years.

Maximum overall results are achieved where a variety of options are evaluated and the most beneficial selected. At Wellington Hospital, some 3500 fluorescent light fittings are to be totally refurbished, employing measures including Silverlux™ reflectors, low-loss ballasts, triphosphor tubes, and, where appropriate, dimmable electronic ballasts (see Box 1, Chapter 9 "Case Studies"), for information on the Silverlux™ silver mirror reflectors.). Annual cost savings are estimated at $200,000, with a payback period of around three years. Illumination levels will not suffer — in the operating rooms, for example, they will be trebled.

Thermal Bridging for Tubes

Fluorescent tube efficiency is greatly affected by the temperature of the tube wall. The ideal maximum tube temperature is 40˚C, whereas temperatures in enclosed fixtures can rise to 50˚C or 60˚C. These temperatures can reduce lamp output by 15% to 20%. Placing heat conducting material against the tube can lower its temperature and thus improve efficiency.

Lawrence Berkeley Laboratory (LBL) in Berkeley, California, has developed two systems to conduct heat away from a standard fluorescent tube (California Energy Commission, 1993). The first is a liquid-filled pouch attached to the top of the tube and the shell of the luminaire. This conducts heat from the tube to ambient air. The second system has a piece of metal snapped onto the top of the lamp that conducts heat to a cooling fin above the fixture and hence to ambient air. Both systems require only a few square centimetres of contact with the tube and thus block little of the potential light output. The very slight loss is more than made up for with improved efficiency. LBL has also developed a simple system to provide a heat conductor for CFLs.

LBL expects these systems will be applied primarily to new fixtures and installations due to the high labour costs of retrofitting. The additional capital cost is very low compared with the fixture's total production and installation costs, so market acceptance should not be a problem.

Compact Fluorescent Fittings

Exchanging incandescent bulbs with compact fluorescents in existing commercial light fittings does not usually present a problem, although the smaller fittings may not be compatible with the bulky lamp holder and ballast. In such cases, it may still be economical to replace the entire fitting, selecting a commercial product specially designed for use with compact fluorescent lamps.

Many luminaires designed for incandescent bulbs and, to some extent, compact fluorescents are not designed with luminous efficiency in mind. Decor is often the chief concern. Consequently, improved luminaire design offers considerable scope for increased lighting efficiency. This could lead to improved lighting levels, greater energy savings, or both.

This, and other related topics, are dealt with in more detail in Part 1, "Domestic Buildings", Chapter 13 "Opportunities in Domestic Lighting".

3.6 Lighting Installations

The design of lighting installations requires considerable expertise and it is not intended, nor indeed possible, to adequately treat the subject in this chapter. However, there are many factors in design that have a direct bearing on energy efficiency and the time has come to look critically at some of the old notions of lighting design and installation from the viewpoint of energy efficiency (Bridgman, 1991). Is there still a requirement for a bland, uniform lighting level of 500 lux, wall-to-wall? Most architects will agree that variety makes for a more pleasant working environment, and light is an essential part of any environment. Of course, the appropriate quantity, and quality, of light must be available where and when it is wanted.

For example, consider a medium-sized office that has four light fittings. One of them is near the door, where no-one does any work. Is that fitting really necessary? Remove it, and an instant energy saving of 25% has been achieved.

In the larger, open-plan situation, a background lighting level of around 250 to 300 lux, boosted up to 500 or 600 lux by task lighting on desks where hard copy is to be worked on, can be a pleasant place to work and can also save large amounts of energy. A level of 500 lux is totally unnecessary for general circulation, sending faxes and filing.

In a typical open plan office area, a lighting installation designed for a uniform 500 lux of illumination may have three-tube 1200 by 600 recessed troffer fittings, with prismatic diffusers, spaced at 3.0 x 2.4 metres. This gives a specific loading of 19.2 watts/m^2.

Substituting or converting to single-tube fittings at the same spacings with high efficiency reflectors and low-loss ballasts, would reduce the specific loading to only 5.8 watts/m^2, and would provide around 250 to 300 lux, which is ample for most purposes. At desks, "task lighting" in the form of desk lamps with, say, an 11-watt compact lamp, would enable illuminance levels on hard copy to be boosted to 500 or 600 lux, with control in the hands of the staff member. The overall power density is still less than 8 watts/m^2.

It should be noted that additional savings may well arise because the task lights will be controlled at the desks and so will not be switched on all the time. Cleaners are not likely to take the trouble to switch them on, so that the overall savings may well be over 60% — and this is without considering any automatic controls. As mentioned earlier, airconditioning savings are additional to savings made on lighting installations.

In both new and retrofit situations, additional electricity cost savings will arise from reduced energy losses in the electrical distribution system between the light fittings and the meter. These losses are proportional to the square of the current. Furthermore, high efficiency lighting can also lead to savings in the initial cost of an electrical installation due to the lower load. Electronic ballasts are doubly economic in this way. If both the improved efficiency and the improved power factor are taken into account, four fluorescent tubes controlled by electronic ballasts may take less current than three tubes with regular ballasts.

3.7 Control Systems

Sophisticated controls for lighting are rapidly gaining acceptance. There can be no doubt that a vast amount of energy is wasted in buildings of all kinds simply due to lights being left on when they are not really needed, or providing more light than is needed, such as when there is a surplus of daylight. Human nature comes into the picture — even where plenty of switches are available, one energy-conscious person's efforts to save energy are usually rendered ineffective by a dozen others who are not quite so enthusiastic.

Many different techniques, each with their own particular advantages and disadvantages, have been developed for both manual and automatic control of lighting (Pool and Brander, 1987). These include:

- flexible switching systems;
- centralised time switching or programmed control;
- dimming systems (using high frequency ballasts);
- occupancy detectors; and

- photoelectric control (on/off or dimming).

What are the relative merits of these systems as energy saving measures? The effectiveness of simply providing more on/off switches is debatable (except for work station task lighting). Switches, and their associated space and wiring requirements, are expensive. Finding a place for each switch or bank of switches is not easy, especially in open plan office areas. The problem is worse still in the case of office floors designed for future partitioning by future tenants because the building designers do not know how this is going to turn out.

An elegant solution to this problem is the MCS 100 system offered by Philips (MCS stands for multi-channel switching). Each luminaire, or group of luminaires, is wired to an infrared receiver that is recessed into the ceiling. All fittings are permanently wired without local switching. On/off or dimming control is effected instead by infrared transmitters that can be either hand-held or placed anywhere on the wall.

The main attraction of this type of system is its flexibility. Entire buildings can be permanently wired for lighting — a modular partitioning system is the only prerequisite. There is certainly potential for energy savings, which will help pay for the system. However, as with all forms of switching that do not involve automatic control by some outside influence, human cooperation is essential if there are to be energy savings.

Most major manufacturers offer high frequency lighting systems (i.e. electronic ballasts) with dimming control, either manual or automatic. The Thorn "controllable visual amenity system" (C-VAS) embraces photocells for daylight input and microprocessor-based programmable clocks to give a comprehensive package of controls to ensure that usage of the artificial lighting is reduced to the bare minimum necessary for performing the tasks concerned.

Dimming can be used to compensate for the aging process. There is a "droop" of at least 10% in light output through the useful life of fluorescent tubes. This has to be allowed for in the original design of the system by some degree of oversizing. As a result, interiors are always overlit when the tubes are new.

Dimmers enable the light output to be turned down at the outset and gradually turned up as output falls. Therefore, there should be a degree of energy saving, especially if control is automatic and combined with daylight sensing.

Occupancy sensing can be performed by passive infrared (PIR) scanners, ultrasonics or a combination of the two. The principle is to switch off the lights, after a suitable time delay, once the detector has ascertained that the room is empty. Sensitivity is such that movement of an arm or leg is sufficient to assure the device that someone is still there.

A very sophisticated scheme, now available from its Wellington developers, employs a sensor that counts people as they enter a room and then counts them as they leave. When the device decides that the last person has left, out go the lights. This gets over the problem of the person who does not move about enough to be sensed by the PIR device.

Arguably, improvements in the energy efficiency of the luminaires themselves should be given priority over controls. The technical and economic performance of efficient luminaires can be calculated in advance with considerable accuracy, whereas there is a large element of guesswork in estimating the benefits of control systems. Performance has to be monitored over a period of time before firm conclusions can be drawn.

Of course, significant energy savings can be achieved (at least theoretically) if energy efficient lighting and controls are used in combination. However, if short payback periods are essential, it may be a case of choosing one or the other. Saving 50% of the energy by efficient lighting means that the payback period of the control system is doubled.

3.8 Occupational Health and Environmental Issues

Before leaving the subject of energy efficient lighting, mention must be made of a growing concern for the health aspects. Despite a high and sustained level of dispute, evidence is steadily accumulating that the "flickering fluoro" is bad for you — even when the flicker is at twice the mains frequency and is further masked by the persistence or "afterglow" of the phosphors.

Experiments recently carried out in England (Wilkins et al., 1989) on 159 volunteers in a government office produced the astonishing result of a 50% reduction in mild or severe headaches or eyestrain where electronic ballasts were incorporated into the light fittings, compared with conventional ballasts. The tests were very carefully carried out in order to avoid any subjective influences.

There has also been some concern raised about the possibility of harmful ultraviolet radiation from fluorescent tubes and tungsten halogen lamps. As far as fluorescent tubes are concerned, there does not yet seem to be any evidence that exposure to UV due to working all day under fluorescent lighting, whether shielded by means of acrylic diffusers or not, can be hazardous.

Tungsten-halogen lamps do emit more UV than ordinary incandescent bulbs, but the general consensus is that the dosage will not be harmful provided the lamp is normally a "reasonable distance" away, although the definition of "reasonable" in this context is not clear. The use of UV filters, which can be plain glass, is recommended — these also double as a precaution against flying splinters in the event of catastrophic failure. Quartz covers should be avoided as these do not filter out UV light.

From the 1950s to the mid-1970s, polychlorinated biphenyls (PCBs) were commonly used in capacitors in electrical equipment, including the small capacitors installed in fluorescent light fittings. PCBs are suspected of being carcinogenic or mutagenic chemicals. They are persistent chemicals that pose a disposal problem. In New Zealand, it is now prohibited to store them. EECA is linking the need to get rid of equipment containing PCBs (in an approved manner) with energy efficiency opportunities. Modernising lighting installations can almost halve the operating cost of a typical 1960s/70s design. EECA has produced a booklet explaining how to identify PCB-containing light equipment and dispose of it properly (EECA, 1994).

References

Baird, G and G Newsam (1986). *Estimation of Energy Consumption in the New Zealand Commercial Sector*, NZERDC Publication P103.

Bridgman, S (1991). "Light fantastic", *Architecture New Zealand*, Jan/Feb 1991, pp 55-58.

California Energy Commission (1993). *Emerging Technologies to Improve Energy Efficiency in the Residential and Commercial Sectors*.

EECA (1994). *Energy Efficiency Opportunities from PCB Phase-out,* produced jointly by EECA and the Public Health Regulatory Service, Ministry of Health, Wellington.

New Zealand Employment Service (1988). *Code of Practice for Visual Display Units*.

Pool, F and W D S Brander (1987). "Energy efficient lighting design and control in New Zealand government buildings", *International Congress on Building Energy Management*, Lausanne.

Waller, G (1989). *The Pitfalls of Tungsten Halogen Lighting*, IESNZ 1989 National Convention.

Wilkins, A J, I Nimmo-Smith, A I Slater and L Bedocs (1989). "Fluorescent lighting, headaches and eyestrain", *Lighting Research and Technology* , (CIBSE Lighting Division), 21(1) 11-18.

Chapter 4
Saving Commercial HVAC Energy

4.1 Introduction

Techniques exist to significantly reduce the energy requirements of commercial HVAC systems. Typical commercial buildings have space conditioning and ventilation energy intensities on the order of 20 to 40 kWh/m^2/yr, peak cooling loads of 5 to 10 m^2/kWh_R and total system efficiencies of 0.4 to 0.5 kW_E/kW_R (COP of 2.0 to 2.5), resulting in installed costs of 120 to 250 \$/m^2 for HVAC equipment (kW_E is electrical energy input, kW_R is refrigeration output).

Through a combination of heat gain avoidance, passive and alternative cooling, improved controls and efficient mechanical equipment, the energy intensity of space conditioning in new construction can be cost-effectively lowered to less than 10 kWh/m^2/yr, peak cooling loads can be lowered to 20 m^2/kW_R, and system efficiency can be improved to 0.20 kW_E/kW_R (COP=5). By downsizing mechanical equipment, capital costs can be reduced to less than \$80/m^2 and the operational costs can be reduced by 50% or more. Opportunities for retrofits to existing buildings also exist.

To achieve these savings, off-the-shelf components and proven technologies are combined in a synergistic manner. Gain avoidance techniques include using advanced glazings and efficient lighting and office equipment. Passive techniques include using evaporative and desiccant cooling. Efficient mechanical equipment includes larger heat exchangers, lower condenser head pressures, parasitic loss reductions, cold air distribution, displacement ventilation and high efficiency axial fans.

More detailed information on the material covered in this chapter can be found in *The State of the Art: Space Cooling and Air Handling* (Houghton et al., 1992).

4.2 HVAC Energy Savings

To date, most of the attention paid to commercial sector HVAC energy savings has been focused on encouraging peak shifting through thermal energy storage. However, large opportunities for both peak power (kW) and energy (kW/h) savings exist in the systematic examination of mechanical systems for efficiency improvements.

While the technical potential is large, many obstacles block the road to HVAC efficiency. The typical design process minimises first cost, tries to avoid tenant complaints by providing overwhelming cooling capacity, shuns technical innovation in favour of familiar methods and minimises system design time through a "cookbook" approach that lends itself more to baking a cake than dealing with the complexities of conditioning a modern building for human habitation. "Optimised" or "efficient" HVAC systems are frequently claimed but seldom delivered.

It is important to consider the interconnections in building systems when seeking an efficient HVAC design (the discussion on climate-adapting buildings in Chapter 2, "Building Envelope and Form" is relevant here). Structural layout, surface treatments, lighting loads and occupancy patterns all affect an HVAC system, which is typically designed by a mechanical subcontractor who has little or no influence on these factors. To take full advantage of the HVAC efficiency potential, an integrated approach that creates both the incentive and capability for building-wide improvements and innovative design is necessary. For example, money saved by installing fewer light fixtures could be used to help pay for a more efficient central chiller plant in lieu of cheap rooftop package units. Performance contracting based on measured energy consumption is one way to encourage efficient systems. Creating such a design environment is a significant task in itself (the importance of the design phase is emphasised in Figure 1.1 in Chapter 1 "Commercial and Institutional Buildings Overview"). This chapter considers the most important technical areas for HVAC system efficiency improvements.

4.3 Load Reduction

Whether a new building is being designed or a retrofit is being contemplated, an efficient HVAC system begins with a minimisation of the loads imposed upon it. It is critically important that the mechanical equipment be selected to deal with the reduced load. In new systems, this is done by downsizing the chillers and air handlers, and by installing appropriate controls in retrofits. If this step is neglected, the result of load reduction will be overcooling of the space and no HVAC energy savings. In particular, chillers and fans should unload through adjustable or variable speed-drive (VSD) equipped motors, and this unloading should be accomplished through the use of reliable sensors and controls. Further information on VSDs is available in Volume 2, Part 8 "General Energy Efficiency Technologies".

A combination of the load reduction measures described below can reduce the total cooling load on a typical building by at least 50%, both in terms of total cooling energy and peak equipment sizing.

Lighting

Reduced lighting power density provides the most convenient and economic opportunity for energy savings in the commercial sector. In the USA this is already widely exploited through utility demand side management (DSM) programs. In most situations, 95% or more of lighting energy turns into heat, which must be removed by chillers. Typical designs call for 20 to 30 W/m^2, although the use of 26 mm diameter (T-8) lamps, electronic ballasts, efficient reflectors and diffusers, and occupancy and daylight controls can easily reduce this to less than 10 W/m^2 (see Chapter 3, "Commercial Lighting"). An *E Source* report describes how to cost-effectively save over 90% of the lighting energy used in the fluorescent systems that dominate commercial office space (Lovins et al., 1988).

Appliances

The fastest-growing portion of commercial building electricity demand is information equipment: computers, copiers, fax machines, printers and scanners. In 1980, commercial buildings were wired for plug load densities of 50 W/m^2. The current figure has doubled to 100 W/m^2 and some computer-intensive spaces now range as high as 200 W/m^2. The use of low-power office equipment such as cold-fusing copiers, notebook computers, and inkjet printers can dramatically lower plug loads from 60% to as much as 90% (Lovins et al., 1988) (see also Chapter 5, "Office Equipment").

Shell

The most attractive means of external gain reduction is through the use of glazing that provides a high shading coefficient (solar gain reduction) and high visible transmission. Tinted glass and clear glass provide each of these properties individually, but spectrally-selective glazings with low-emissivity coatings or Heat Mirror^{TM} suspended films can do both at lower cost and greater reliability than mechanical shading systems. Gain control films are also available to retrofit existing windows. Since external heat input moves cooling loads across a building's perimeter throughout the day, avoiding these gains has the additional benefit of simplifying zoning requirements. Other external gain reduction strategies include:

- optimising building shape and orientation;
- planting local vegetation;
- using light-coloured surface treatments for the building and non-reflective surfaces for the surrounding areas;
- roof wetting;
- reducing infiltration; and

- increasing insulation.

Insulation in commercial buildings needs to be used with care to ensure it is not counterproductive — see Section 2.9 of Chapter 2 "Building Envelope and Form".

4.4 Efficient Mechanical Equipment

Heat pumps are the most common cooling technology used in commercial buildings. An extensive description of heat pump technologies is provided in Volume 2 (see Chapter 3, Part 8 "General Energy Efficiency Technologies"). Heat pump applications are also covered in this volume (see Part 1 "Domestic Buildings", Sections 6.6, 8.3 and 11.4).

Heat Exchange

Conventional mechanical cooling can be improved by reducing the temperature "lift" that the refrigerant is "lifted" by the compressor. The simplest way to do this is to increase the size of the heat exchangers (condenser, evaporator, cooling coil, cooling tower) so that the temperature approaches are closer, and less over-cooling and over-heating of the refrigerant become necessary. A good rule of thumb is to oversize the chiller evaporator and condenser by a factor of four from their standard size. This will give a lower life-cycle cost system than those with standard heat exchangers.

One important technique is to use water-cooled condensers (with cooling towers) or evaporative condensers instead of air-cooled condensers for heat rejection. These allow the heat rejection temperature to be at the wet-bulb air temperature, which is several degrees lower than the dry-bulb (normal) temperature to which air-cooled condensers reject their heat. The temperature approaches (between condensing refrigerant or condenser water temperature and rejection temperature) can be closer for water-cooled systems due to the better heat transfer performance of water compared to air.

The trade-off is increased maintenance costs for water-cooled systems versus much higher (usually about doubled) energy costs for air-cooled systems. The capital costs are usually slightly lower for water-cooled condensers as well, compared to air-cooled condensers.

Air Systems

Air handling systems provide considerable scope for power reduction. Typical field efficiencies of air handling units range from 20% to 50%, and the duct systems they push air through impose a significant 750-1000 Pa (75-100 mm water) of static pressure. This sometimes results in fans that consume more energy than their neighbouring chiller compressors. However, careful fan selection and installation allows 75% to 85% fan efficiency, and duct static pressure can be reduced to under 375 Pa through improved aerodynamics, reduced dampering and lower airspeeds. Significant energy savings can also come from applying these techniques to reducing cooling-tower fan and chilled and condenser water pumping energy costs.

Leaky ducts, dirty filters, stuck dampers and so on, are a major source of inefficiency in air handling systems. Duct sealing can be labour intensive and expensive. In future, this may become cheaper and hence more readily available as a very cost-effective measure. Aerosol compounds are being developed for internal duct sealing (California Energy Commission, 1993). These are sprayed inside ducts and seal in much the same way as flat tyre aerosol cans fix a punctured tyre. Holes larger than 10 mm have to be sealed by normal tape and mastic means, but the aerosol can deal with smaller holes and is particularly useful with diffuse leaks. Filter paper placed over the supply registers captures unused aerosol. Further information on fans and their motors is available in Volume 2 (see Chapter 7, Part 8 "General Energy Efficiency Technologies").

Controls

Like most other HVAC technologies, control systems can have both positive and negative effects on system efficiency. Strategies such as optimal chiller start/stop, scheduling, chilled water temperature reset and chiller lockout can save large amounts of energy. Unfortunately, reliance on a computer to drive a building's systems can also result in energy waste, such as when a malfunctioning sensor or thermostat calls for simultaneous heating and cooling, maintenance staff override the control system for night comfort, or a myriad of other problems go unnoticed or unrecognised. Still, intelligently-applied HVAC system controls can deliver at least 20% to 30% energy savings compared to standard building practice (see the St Lukes shopping centre case study in Section 9.6, Chapter 9 "Case Studies").

4.5 Passive and Alternative Cooling Methods

There are a number of methods for cost-effectively reducing the load on mechanical cooling systems. Some are only applicable during certain times of year (e.g. when ambient temperatures are low enough), although others are effective year round. The California Energy Commission has put together a good summary of developments in alternative cooling methods (California Energy Commission, 1993).

Economisers

An "air-side economiser" directs a flow of outside (cool) air into the building when it can provide useful cooling. This technique is commonly used in areas where ambient temperatures and enthalpies are regularly low enough for use. In Wellington, for example, an air-side economiser can provide up to 77% of total cooling energy (Usibelli et al., 1985).

When for some reason air-side economisers cannot be used, "water-side economisers" are an appropriate alternative. These utilise the evaporative cooling generated by the cooling tower (part of a normal mechanical cooling system) to cool the building directly, either by circulating evaporatively-cooled tower water directly through the building's chilled water circuit, or via a heat exchanger.

Absorption Cooling

Absorption cooling is a well-established technology and uses heat to regenerate an absorbent that produces a cooling effect. Absorption provides mechanical cooling without the use of chlorofluorocarbons and effectively substitutes a natural gas-driven (or other heat source) regenerator for an electrically-driven compressor. More information on absorption cooling is provided in Volume 2 (see Chapter 3, Part 8 "General Energy Efficiency Technologies"). The cost-effectiveness of this technique depends on the relative costs of electricity and heat. In industrial areas, a waste heat source can provide the heat. Combining absorption and vapour compression cooling (in two paralleled, half-sized units) can often offer the lowest-cost method of providing mechanical cooling (Duffy, 1990).

Evaporative Cooling

Evaporative cooling uses water sprays or wetted media to cool supply air either directly or indirectly, allowing temperatures to approach the "wet-bulb" temperature of the ambient air. This is a well-established technology that can either totally supplant conventional mechanical chilling in climates where the air is consistently dry, or supplement conventional chilling during periods of occasional dryness. The temperature reduction available from evaporative cooling is much greater with drier incoming air.

Direct evaporative cooling humidifies the air stream as it is reduced in temperature, while indirect evaporative cooling adds no humidity. Indirect evaporative units often use indoor air that must be exhausted as the cooling media, which results in greater cooling than when using warmer outdoor air. The trade-offs are that indirect cooler capital costs are generally higher and the heat exchange is not as effective as direct evaporative cooling. Indirect evaporative cooling can be combined with vapour compression cooling in single units (White, 1988).

Both methods consume water for evaporation and electric power for fans, but the electrical consumption for either type of evaporative cooling is about 75% lower than for conventional mechanical cooling (Watt, 1986).

Desiccant Drying

Desiccant drying is a technology that is widely used in industrial applications, although less so in commercial applications. It is effectively evaporative cooling in reverse, where the air streams are reduced in humidity but increased in temperature. (A source of heat energy is needed to regenerate the desiccant after it has absorbed water from the air.) The dried air streams can then be easily cooled by heat exchange with ambient air and evaporatively cooled to a much lower temperature.

The addition of desiccant drying as a first stage makes evaporative cooling much more widely applicable and effective. This technology may allow the total phase-out of CFC-driven cooling worldwide (Meckler, 1991).

Passive Cooling

A number of cooling techniques that work in concert with the natural environment — passive ventilation, ice ponds, night-time water sprays, earth berming and the use of shading and thermal mass — have been known for centuries (see the discussion on climate-adapting buildings in Chapter 2, “Building Envelope and Form”). Although these techniques are most commonly applied to smaller, residential structures, they can also be used with larger buildings. Passive cooling is more an architectural art than an engineering science, but should be considered wherever low-energy cooling is the goal.

4.6 Conclusions

A combination of gain avoidance (both internal and external), more efficient mechanical cooling (with parasitic power reduction), appropriate supplemental alternative cooling and improved controls, can provide up to 90% energy savings.

With capital cost reductions from HVAC downsizing (due to reduced loads), increased rentable space (from smaller and quieter equipment) and additional benefits (such as the potential for circulating chilled water in fire-protection sprinkler piping and reducing duct sizing by using low-temperature air), the cost-effectiveness of these measures becomes very attractive.

An example of these techniques in practice is a cost-effective commercial building retrofit demonstration project sponsored by a large electric utility, which showed a 93% reduction in design HVAC energy use (Pacific Gas & Electric Company).

References

California Energy Commission (1993). *Emerging Technologies to Improve Energy Efficiency in the Residential and Commercial Sectors*.

Duffy, G (1990). “Gas and electric chiller combo trims guest quarters’ utilities”, *Engineered Systems*, Nov/Dec. 1990, p.63.

Houghton, D, et. al. (1992). “The state of the art: space cooling and air handling”, *E Source*, Boulder, Colorado.

Lovins, A et. al. (1988). The state of the art: lighting, *E Source*, Boulder, Colorado.

Lovins, A et. al. (1990). The state of the art: appliances, *E Source*, Boulder, Colorado.

Meckler, G (1991). “Desiccant cooling systems and air quality, energy resources, and CFC use”, *IEA/CRD/EUWP Workshop on Air Quality, Desiccants, and Evaporative Cooling*, Orlando, FL, January 14-16, 1991.

Pacific Gas and Electric Company, ACT2 (Advanced Customer Technology Test for Maximum Energy Efficiency), Pacific Gas and Electric Company, San Francisco, California.

Usibelli, A et. al. (1985). *Commercial-Sector Conservation Technologies*, Lawrence Berkley Laboratory report 18543. [The study was done for San Francisco, which is climatically analogous to Wellington.]

Watt, J R (1986). *Evaporative Air-Conditioning Handbook*, (2nd ed.), Chapman and Hall, New York.

White, G, (1988). “Hybrid indirect evaporative air conditioning”, *AIRAH Conference*, Sydney, May 1988.

Chapter 5
Office Equipment

5.1 Introduction

A dramatic change has occurred in the way information is processed in buildings over the last 15 years. While there has been rapid growth in paper-based technologies (printers, copiers and fax machines), there has also been a partial transition from paper tasks to screen-based tasks. In many businesses, office automation has been decentralised, and personal computers, local printers and copiers have displaced mainframe computers and centralised printing and copying.

The office automation revolution has been one of the more significant factors affecting changes in energy intensity in the commercial and institutional sector and poses a number of challenges for building professionals. The electrical engineer has to provide for growing power demands. The lighting designer has to rethink strategies to control glare from artificial lighting on vertical screens, while still providing adequate illumination for paper tasks. The architect needs to prevent windows from becoming sources of both glare on screens and unwanted solar gain to compound the internal heat gain from equipment. The airconditioning designer has to contend with increased heat gain from office automation equipment, which must be handled by the general airconditioning system rather than by the dedicated plant that served the centralised mainframe computers of the past.

In some instances, interior lighting designs to cater for screen-based tasks have been more energy intensive than standard designs. Coupled with the internal heat gain from office equipment, which in some buildings exceeds that due to either the occupants or the lighting, the need for airconditioning has increased. In the past decade, a noticeable decline in heat demands for space conditioning has been offset by increased cooling requirements in many buildings.

This chapter reviews some alternative office equipment technologies and their effect on energy consumption trends. More information on efficient office equipment can be obtained from the references listed at the end of this chapter. A good starting point is a Californian report (California Energy Commission, 1993).

5.2 Trends in Equipment Use

The penetration of personal computers into the New Zealand market lags behind other developed countries. At the end of 1991, New Zealand had one PC for every 9.8 people. In the US and Canada, there was one for every 3.85 people. It is estimated that the 425,000 installed personal computers in New Zealand in 1991 may reach 1 million by 1997 (National Business Review, 1993). A sizeable proportion of this increase is expected to occur in homes.

Surveys of commercial buildings in New Zealand indicate an uneven distribution of personal computers. In some buildings, there is one PC per workstation, with a number of workstations also having a dumb terminal connected to a mainframe computer. In other offices, one PC may be shared by three or more users.

Office equipment energy requirements and the resultant heat gains will change under two opposing influences. First, there is likely to be further uptake of equipment as more uses are developed and more powerful machines become available. Second, the energy consumption of the machines will decrease as technology advances. BRECSU (1993) predict that “worst case” equipment power demands per person may rise from a 1992 level of 300 watts to about 350 watts before falling to 150 watts after 2000.

Given the likely reduction in the power requirements of personal computers (see Section 5.4 below), it is concluded that some building computer loads in New Zealand have nearly peaked and may decline in the next five years as more efficient equipment replaces current models. In buildings with a low density of personal computers, significant increases in electrical load are anticipated over the next five years.

In the USA, the Environmental Protection Agency (EPA) surveyed PC use and found that 20% to 40% of computer users leave their machines running continuously (*PC Magazine,* 1993). The EPA also found that about 40% of American corporation's computers stay on 24 hours a day, 365 days a year under the mistaken impression that this saves wear and tear on the equipment (*Infotech Weekly,* 1993).

In New Zealand, several building surveys have identified similar levels of waste. Furthermore, analysis has shown that about 60% to 70% of PC energy consumption occurs when the machines are not being used (Newsham and Tiller, 1992). Machines are frequently left on overnight or for extended periods during the day when not being used. The EPA also estimates that 80% of the time a monitor is on, no one is looking at it. The operation of other equipment, such as photocopiers and printers, depends on the building management practice. Anecdotal evidence suggests that shared printers and photocopiers are more likely to be left on after hours than personal computers.

The practice of leaving computers on reportedly derives from the notion that the large soap-lubricated hard drives of old mainframe computers performed more reliably when left running (*E Source News*, 1992). Modern miniature hard drives function reliably even if turned off frequently. Some uncertainties do remain about whether thermal cycling (turning on and off) affects internal components in the long run, but manufacturers such as IBM and Hewlett Packard are not unduly concerned about this.

5.3 Power Demands and Internal Heat Loads

The use of nameplate ratings to estimate actual power demands is unreliable and can lead to over-sized electrical distribution equipment and airconditioning systems, which will have a major impact on capital outlay, particularly for airconditioning plant. Surveys have provided useful information on the range of actual power requirements and the ratio of average power to nameplate rating (BRECSU, 1993). Average power typically varies by a factor of 2 to 4 for each equipment category, and the ratio of average power to nameplate rating varies from 10% to 95% (see Figure 5.1).

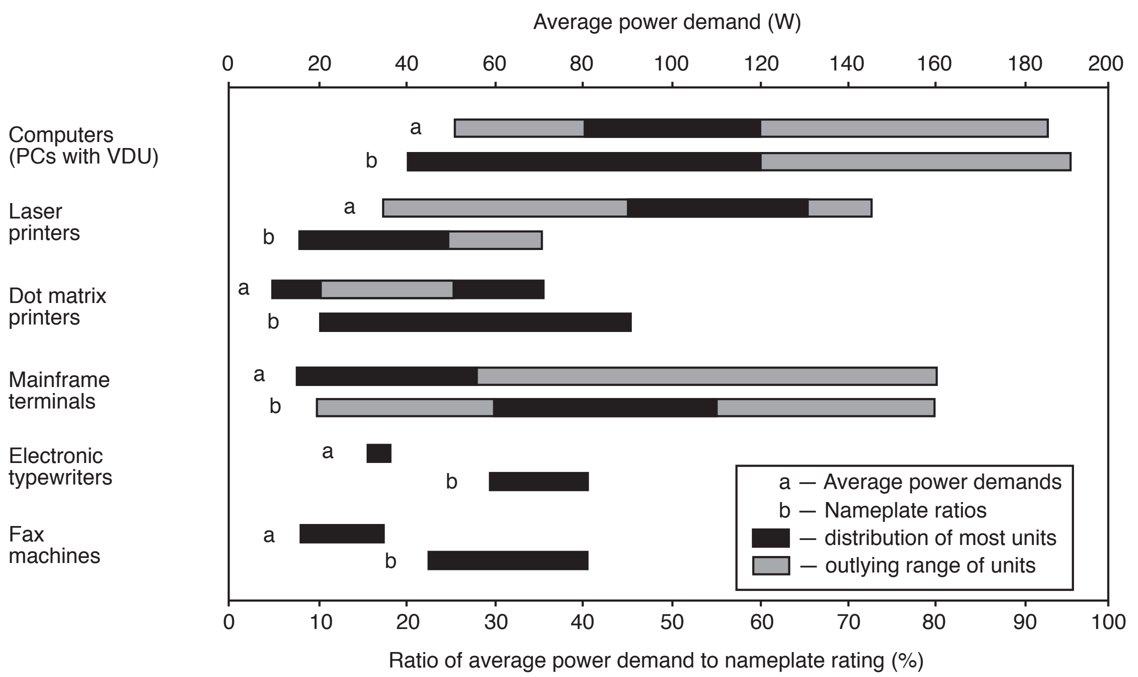


Figure 5.1: Equipment power demands

In offices with a high PC density, peak electrical loads for office equipment can exceed 50 W/m^2 and much of the equipment is not switched off. Like lighting, reductions in office equipment loads could feed back into less energy use by HVAC systems. Table 5.1 shows "worst case" power demands for equipment in an office of 50 people.

Type of Equipment	Demand per person (Watts)
Computer terminal	170
Photocopier	30
Printer	65
Others	30
TOTAL	295

Table 5.1: "Worst case" office equipment power demands (after BRECSU, 1993)

5.4 Desktop Personal Computers

Energy use per instruction execution capability has fallen by two to three orders of magnitude since the 1960s, but average power consumption per PC has stayed the same or risen because of huge increases in the computing power of the average machine (Shepard et al, 1990).

Available models of desktop personal computers have widely varying levels of power consumption, ranging from more than 200 W down to about 30 W (Norford et.al., 1990). It appears that present average power consumption is about 132 W per unit. Once switched on, personal computers effectively appear to be constant power-consuming devices.

Present desktop personal computers use "n-channel metal-oxide semiconductors" (NMOS) rather than the "complementary metal-oxide semiconductors" (CMOS) used in laptops. Both types draw similar amounts of power when a transistor is switched, but CMOS requires almost no power when inactive. Memory chips, for example, are inactive most of the time. Widespread use of CMOS chips in desktop systems will dramatically reduce energy consumption.

Screen-saver software is only intended to save the screen phosphors by switching off the high-voltage beam that illuminates the screen. The software does not significantly reduce electricity use and may, in fact, waste power if the screen is left on because it gives the impression that the screen is switched off. Screen-saver software should not be confused with a genuine power-management unit, which actually disconnects most of the power supply to the monitor. In addition to the electricity savings, power-management units reduce the users' exposure to electromagnetic fields and screen flicker. These devices can eliminate much of the wasted power when computers are not in use.

The US EPA is tapping into the potential for desktop PC power-management savings with its Energy Star Computer Programme. The programme allows computer manufacturers to use a special EPA logo to promote machines capable of going into a low power state of 30 watts or less for either computer or monitor. Nearly 100 PC vendors have signed on as Energy Star partners or allies (*Infotech Weekly,* 1993) and these companies represent 70% of the US computer market and 90% of the US laser printer market (Hoffman, 1993).

Laptop computers typically consume about an order of magnitude less power than desktop personal computers. Technologies such as "flat screens" (comprising either liquid crystal display (LCD), gas plasma or electroluminescent displays), low-power-consumption disk drives, CMOS chips and power management features have enabled designers to build machines with high computing power but low power consumption.

Many of these technologies are applicable to desktop personal computers and may pave the way to much more efficient desktop machines. Depending on whether strong market demand for energy efficiency materialises, efficient hardware technologies that may appear in desktop machines include the SL chip (which can go into a very low-power rest state and then resume activity where it left off without rebooting), improved drives and advanced flat panel displays.

The market evolution of monitors may be heavily influenced by growing concerns about the possible health effects of electromagnetic fields produced by cathode ray tubes (CRTs).

LCD displays have the lowest power demands of all commercially available screens, but they are only comparable with other screens if backlighting is included. Power use depends mostly on the number of active pixels. Colour is technically feasible, but expensive. Electroluminescent displays consist of a matrix of crossed rows of electrodes with a layer of phosphor between them. A voltage applied between an "x" and "y" electrode causes the phosphor at the intersection to glow. Contrast ratios of 25:1 are available and the 160° viewing angle is superior to LCD and gas plasma displays. Plasma displays offer exceptional resolution, high contrast ratios of 100:1 and only one colour, but substantial greyscale. Power is proportional to the number of lit pixels. Table 5.2 shows indicative power demands for various screen types.

Screen type	Power demand (W/cm^2)
Liquid crystal display (no backlight)	0.00002 - 0.0002
Liquid crystal display (with backlight)	0.02
Electroluminescent	0.02 - 0.06
Gas Plasma	0.016 - 0.23
Cathode ray tube	0.2

Table 5.2: Indicative power demands for computer screen types

A combination of power management and adoption of laptop-type hardware improvements should enable average desktop power demand during typical operating hours to be reduced to about 20 W with an active matrix colour display, and to about 55 W using a CRT display. These numbers are substantially above the power requirements of present laptops because they assume much larger displays —375 mm (15 in) — than are presently used in laptops (Norford 1992). All hardware and power management improvements are expected to have little or no additional costs, with the exception of advanced flat panel display modifications (Zoi, 1992). Desktop LCDs are currently four to five times more expensive than CRTs of the same size, but increasing production volumes are predicted to reduce incremental costs to between several hundred and zero US dollars within a few years (Ledbetter and Smith, 1993). Commercialisation of power management and laptop-type hardware and software features is occurring.

5.5 Printers, Copiers and Facsimiles

Commercially-available printer and copier technologies have a wide variety of energy consumption characteristics. Copiers and laser printers typically consume 0.3 to 2.1 watt-hours (Wh) to print an image. Most of the electricity used is "standby" energy, that is, energy consumed regardless of how the machine is being used. Thus, most of the effort to lower energy use is directed toward reducing standby energy use.

It should be noted that both printing and standby energy, however, are dwarfed by the approximately 20 Wh required to manufacture a sheet of paper (Nordman, 1994). In monetary terms, a sheet of paper costs more than ten times the electricity required to image one side of it. Equipment and office practices that conserve paper (e.g. imaging both sides, managing more information electronically) are likely to save more energy and money than improvements in the energy efficiency of equipment.

At present, inkjet technology is the most energy-efficient commercial technology for printers and faxes. Inkjet machines rely on print heads that spray ink on paper from tiny, electronically-activated orifices. When compared with the more popular laser printers and faxes, the primary disadvantages of inkjet technology are print speed and quality. Continuing improvements in printhead design, the use of multiple printheads and image smoothing capability should enable these machines to compete for print quality and speed within a couple of years. Colour inkjet printers are presently comparable in speed and quality to colour laser printers — *PC Magazine* reviewers stated that “a magnifying glass is required to detect the difference between text samples printed on the Hewlett-Packard PaintJet XL300 and a LaserJet” (*PC Magazine*, 1992). When combined with their very simple design, reliability and lower-than-laser technology cost, inkjet machines should prove attractive.

The printing and standby power consumption of inkjet printers are typically less than 30 W and 10 W respectively, compared to laser machines, which typically consume more than 500 W and 50 W respectively (Ledbetter and Smith, 1993). The inkjet machines are significantly lower in cost than laser machines, but a direct comparison is not appropriate as the features of machines utilising the two technologies are markedly different.

Inkjet machines are currently gaining in the lower end of the market (in terms of print speed and quality), largely due to their low cost. They are expected to continue gaining market share as their speed and print quality improve (Nordman, 1993). Regulatory measures are probably not needed to promote use of these machines, but some targeted demonstrations and education would be useful.

5.6 Improved Cold-fusing and Low-energy Fusing Copiers, Printers and Faxes

Most imaging office equipment that use xerographic processes, such as copiers, laser printers and laser fax machines, use a hot fuser to fix an image to paper. High temperatures (>150˚C) are required in the fuser element to fuse toner to paper. Such high temperature demands have meant high-power fuser elements, which can exceed 1000 W during photocopying for a typical mid-range, floor-mounted photocopier. The fuser element is by far the biggest energy user in these machines (California Energy Commission, 1993).

Technologies exist that could substantially reduce this component of a machine’s power consumption. Cold pressure fusing and Delphax ion-deposition imaging are two developing technologies that eliminate the need for a hot fuser. Cold pressure fusing fuses toner to paper with high-pressure rollers, while Delphax ion-deposition imaging uses an entirely different process for forming an image on the image drum; the image is then cold pressure-fused to paper. Alternatively, infrared or microwave heating could be used to directly heat a small zone rather than an entire fuser roller, or thin-belt fusers with much less mass requirements for hot fuser printing could be used (Ledbetter and Smith 1993).

Cold pressure fusing is already commercially available, but has limitations in that pressure-fused images tend not to adhere as well to paper as hot-fused images. Therefore, the technology needs improvement before wide-scale application is possible. Delphax technology is also currently available, but is presently used only in high-volume printing machines. Technologies other than cold pressure fusing and Delphax will require further development before they can be commercialised.

Technology costs for all of these options are uncertain but are likely to be low. For Delphax ion-deposition imaging, as presently used in high-volume printing machines, the technology is highly cost-competitive with other high-volume machines (Ledbetter and Smith, 1993). If it could be successfully scaled down to lower-volume machines, it might retain its cost competitive advantage.

5.7 Accelerating the Uptake of Energy-efficient Office Equipment

The market demand for energy-efficient office equipment in New Zealand appears to be low at present (Jackson, 1994) and the introduction of energy-efficient products tends to be supplier-led. There is likely to be a significant increase in the energy efficiency of the office equipment population as suppliers incorporate new, improved features, partly as a result of overseas programmes such as “Energy Star”. A major challenge is to persuade IT professionals and users to activate the power-down features in new equipment.

Although New Zealand is unable to affect the technical development of equipment, it can take some steps to increase market demands for energy efficient models. Initiatives that would assist uptake include:

- development of government purchasing guidelines to generate a significant consumer demand;
- development of a labelling scheme/education programme to encourage purchasers to factor energy use into their purchase decisions.

The initial cost and the annual operating costs of a PC are roughly comparable to those of a large household refrigerator (Harris et al, 1988). Many countries, including New Zealand, put efficiency labels on refrigerators and a similar scheme could be applied to computers and peripherals; and

Any attempt, however, to develop efficiency standards is likely to be overtaken by the rapid rate of innovation and short product life cycles.

References

BRECSU, (1993). Energy Efficiency in Offices — *Small Power Loads, Energy Efficiency Office*, Department of the Environment, UK.

California Energy Commission (1993). *Emerging Technologies to Improve Energy Efficiency in the Residential and Commercial Sectors*.

E Source News, Tech. update, September 1992.

Harris et. al. (1988). *Technology Assessment: Electronic Office Equipment LBL-35558 Rev.*, November 1988. Cited in *State of the Art Technology Atlas Appliances* , August 1990 edition, E Source Inc., Colorado.

Hoffman, (1993). *Proceedings of E Source members forum*, 4-6 October 1993, Aspen, Colorado.

Infotech Weekly, 18 October 1993.

Jackson (1994). "Public sector uptake of green PC's 'bit of a flap'", *Computerworld NZ* 14 February 1994.

Ledbetter and Smith (1993). *Guide to Energy Efficient Office Equipment*, Berkeley, CA, American Council for an Energy Efficient Economy.

National Business Review, 17 September 1993, p52.

Newsham and Tiller (1992). A Case Study of the Energy Consumption of Desk Top Computers, *Procs. IEEE Industry*.

Nordman (1993). Quoted in California Energy Commission, 1993.

Nordman (1994) Quoted in FEMP Focus, 1994

Norford et. al. (1990). "Electricity use in information technologies", *Annual Review of Energy* 15:423-453.

PC Magazine, 25 May 1993, p110.

Shepard et. al. (1990). *The State of the Arts Appliances*, Rocky Mountain Institute, Colorado.

Zoi (1992). Pers. comm., quoted in California Energy Commission, 1993.

Chapter 6
Management, Monitoring and Targeting

This chapter covers energy management programmes for commercial and institutional buildings. Targets, which are also covered here, were raised in Section 1.3 of Chapter 1 "Commercial and Institutional Buildings Overview". Statutory targets, or standards, are covered in Chapter 8 "Barriers, Codes and Standards". Volume 2, Part 7 "Manufacturing and Minerals", contains four chapters relevant to the material discussed here. Three of the four chapters refer to target setting, sector studies and monitoring, while the fourth covers good housekeeping. The housekeeping material on steam systems, for example, will be helpful to institutional building managers.

6.1 Introduction

The operation of a building can impact on energy use considerably, with well-operated buildings using significantly less energy than those that are poorly operated. The interaction of building owners, operators and managers with their buildings are all important. Some of the technologies and techniques available to help building owners etc. improve the operation of buildings from an energy perspective are:

- preventive maintenance;
- energy management programmes;
- monitoring and targeting; and
- building energy management systems.

Each of these technologies and techniques are outlined below. Before discussing these, it is important to emphasise the human factor in building management and the basic low technology considerations that can save energy.

The response of people to their environments is an important consideration, as "hardware" approaches to energy management problems are often defeated by building occupants. Tight seals around doors and windows are useless if doors and windows are kept open. Building occupants have no choice but to turn all of the lights on or all of them off if there is only one lighting zone and no individual controls. Building managers, operators and occupants should ensure that the human factors are well considered in an energy management programme.

A good deal of the energy used in buildings is wasted because of inefficient practices or behaviour at variance with design assumptions. Even without bringing in major new equipment or sophisticated computer controls, simple technology and management changes such as the following can improve energy use:

- schedules for turning off lights, fans, heating/cooling systems;
- automatic timing controls for heating and lighting;
- scheduling of building usage to concentrate activities;
- emphasis on the need for routine maintenance, such as changing filters and cleaning light fixtures;
- scheduling of janitorial services to avoid lighting the entire building at night for this purpose;

- training for maintenance and operations people to sensitise them to practices that are wasteful of energy;
- preparation of materials (e.g. checklists) to be used routinely to identify potential problem areas; and
- turning off lights by individual occupants.

6.2 Preventative Maintenance

Energy is consumed on a daily basis and it is the accumulation of small, day-by-day losses that create significant monthly or annual losses. The standard of daily care and maintenance is an important contributor to the long-term operational efficiency of any facility.

Getting existing plant operating efficiently is usually more cost-effective than investing in new equipment to save energy and costs. Consequently, the starting point should be to ensure that plant is operating at peak efficiency by carrying out adequate maintenance.

Human beings have always faced the problem of equipment wearing out. The use of lubricants, bearings and hardened surfaces followed naturally from the invention of the wheel. Pre-industrial and industrial societies progressively developed a form of preventative maintenance (PM). Engineers today define the early form, or first category of PM, as classical preventative maintenance (CPM). These activities include lubrication, inspections, changing worn parts, minor adjustments, cleaning and so on. The need for CPM is what led to the hiring of maintenance staff in the first place.

During the twentieth century, two new categories of preventative maintenance have been created, namely planned maintenance and predictive maintenance:

- *Planned Maintenance*

  Because of an increased requirement to guarantee public and occupational health and safety, public agencies have been created to establish and enforce regulations concerning facility maintenance. Such regulations often require planned maintenance activities on certain equipment and a record system that guarantees it is carried out. This type of PM is called planned maintenance and is required, to some extent, in nearly every facility. Examples of planned maintenance include boiler inspections, lift inspections, and fire and safety equipment inspections.

- *Predictive Maintenance*

  New technologies that permit non-destructive testing and measurement have increased our ability to evaluate the condition of equipment and predict the need for maintenance attention. Maintenance staff are increasingly using these predictive tools in facilities management, creating a third kind of PM, called predictive maintenance. Examples of predictive maintenance are oil sampling, infrared scanning and vibration analysis.

As a result of these developments in PM, the task of maintenance has become far more complex and the technical and management skills required have increased. Maintenance is becoming a pro-active rather than simply a reactive discipline. The dominant concern is no longer dealing with crises such as breakdowns. Instead, the emphasis is on developing concepts of active maintenance management that anticipate and prevent such crises. Thus, modern preventative maintenance consists of those inexpensive activities which, when performed regularly, as needed, help to avoid costly consequences.

Focusing on costly consequences (such as unexpected downtime, warranty failure, premature wear-out, personal injuries, fires, loss of customer goodwill and so on) helps to identify inexpensive activities that can be performed at regular intervals, which will help avoid such consequences in the future.

The aim is to put in place a system that generates the PM activities identified as enabling costly consequences to be avoided. By performing the activities at regular intervals, they can be planned and scheduled into future maintenance programs. By using this approach and building up in small steps, a PM program will pay for itself very quickly through reduced breakdowns, failures and energy consumption.

6.3 An Energy Management Program

An energy management program is a strategy for reducing the energy costs in a building (or even an organisation). It should detail all the steps necessary to secure energy cost savings and provide the basis to start saving money and achieve results. The need for an energy management program is not always apparent.

An energy management program can be described in 10 steps. These are outlined below.

1 *Commitment from senior management to energy management.*

Resources of time and money are required for successful energy management. The commitment of senior management is required to secure these resources and make energy management a focus in the organisation.

2 *Make someone responsible for managing the organisation's use of energy — an energy manager.*

People in organisations tend to be extremely busy with their existing work and have little time to devote to energy management. Therefore, someone must be made responsible for the use of energy in an organisation in order for reductions in energy costs to be made. This can be a full- or part-time position, as required.

3 *Identify how energy is being used now — an energy audit.*

An energy audit provides a snapshot of how energy is being used in an organisation at the time of the audit, determines how energy was used in the recent past and then identifies ways to reduce the energy costs. It is necessary to conduct an energy audit to provide direction to the energy cost saving efforts and to provide a basis for comparison of results later.

4 *Allocate responsibility for energy use.*

Allocate responsibility for energy used in different parts of the organisation to the appropriate line manager to ensure that the various users of energy in an organisation fully support the energy manager.

5 *Start implementing energy management measures, no-cost measures first.*

In most organisations, some simple "housekeeping" measures can be implemented to start making energy savings. Examples include turning off unnecessary lights, shutting doors and windows and stopping compressed air and steam leaks. These low-cost measures can often reduce an organisation's annual energy consumption by about 10%.

6 *Start a monitoring and targeting system.*

Monitor how and when energy is being used on an ongoing basis and target reductions in energy cost and consumption.

7 *Implement low, medium, then capital cost energy management measures.*

At this stage of the plan, the organisation should be seeing some results and it should be possible to secure funds to invest in energy management projects. Start with the projects with the shortest payback periods or the lowest investment costs.

8 *Involve other staff in energy management.*

Some energy cost savings come from changes in human behaviour. Help staff become, and stay, motivated to make energy savings by involving them in the program.

9 *Develop energy management skills.*

Motivation for the energy manager is also vital to securing ongoing reductions in energy costs and consumption. Assistance and discussions with other experts can assist with this motivation.

10 Regularly review progress.

Never assume you have done all that is possible or cost effective. Technology is always improving, a major refurbishment may be on the horizon, etc. Regularly go back to the start and review commitments and systems.

6.4 Monitoring and Targeting Systems

Monitoring and Targeting (M&T) software systems in Britain have established themselves over the past ten years as a valuable tool in helping realise a 5% to 20% energy saving through closely monitoring and targeting energy use. These savings can often be achieved through measures that require little or no capital outlay.

M&T systems are essentially management information tools that help save money by closely monitoring energy use and highlighting waste or bad trends for prompt corrective action. These systems can be manual or computer-based, although they are almost invariably the latter. The software operates on a desktop computer that uses information from invoices, meter readings, the mainframe computer, utility billing tape, energy management systems or directly from the meter via a modem.

The majority of the M&T systems used in multi-site organisations are computer-based and use invoice or meter reading information manually entered into the computer. These are used to save money, energy and time, and promote more informed management.

A good monitoring and targeting system should be capable of:

- checking the energy bills for faulty readings and incorrect rates;
- analysing and correcting energy use to appropriate variables that may affect energy use, i.e. outside temperature, production, shifts, etc.;
- comparing energy use against industry norms, budgets or targets;
- picking up and reporting (by exception) on unfavourable trends;
- accurately calculating savings to date from energy saving measures;
- undertaking tariff analysis to ensure that energy is purchased as cheaply as possible; and
- providing graphical and tabular performance reports for dissemination throughout the organisation.

The task of M&T is becoming easier and the results more useful as building energy management systems become more sophisticated.

6.5 Building Energy Management Systems

Building management systems permit the operation of many types of plant and systems in a commercial building to be easily controlled. They also provide a method for achieving good comfort levels for occupants, optimisation of plant and, of most relevance here, the control of energy use.

In a building, it can be difficult to ensure lights are turned off at the end of the day or that the HVAC system remembers that daylight saving has arrived again. BEMS make this possible by having building systems controlled by electronics and computers. Thermostats can be set by the building manager from a central computer. Lights can be scheduled to turn off at night when all employees would normally have left the building. The possibilities for control are large as BEMS with highly sophisticated control mechanisms continue to develop.

New intelligent meters, lower-cost metering equipment and cheaper BEMS system outstations mean that automatic monitoring of energy performance of industrial plant or buildings is becoming more widespread. If an energy overspend can be detected close to its occurrence, more money will be saved than if this were detected through weekly meter readings or monthly energy bills.

M&T systems are now becoming truly integrated systems able to accept data at different frequencies from a wide variety of sources. In many ways, the M&T system starts where the BEMS system leaves off: it can monitor and report on the energy performance of all sites and processes, with or without automatic data recording equipment.

Energy use information can be acquired from intelligent meters with integral data logging facilities or on-site data loggers that accept pulses from electricity, gas, oil, water, steam or heat meters and measuring other variables such as temperature and production volume. Alternatively, relevant information can be transferred from BEMS systems that may already be used for monitoring this information or can be extended.

The M&T system continuously monitors performance utilising building and process energy signature techniques and altering or alarming the user once the energy performance has exceeded some predetermined condition. The variables that energy consumption is measured against could be production (on industrial sites) or external temperature (in buildings). If required, this half-hourly acquired data can be reconciled against the actual bill, which is particularly useful if bills are frequently estimated.

6.6 Conclusions

During the last decade, M&T software systems have been widely used in the UK by industry, commerce and central and local government. They are particularly useful in monitoring energy performance and identifying waste that can be remedied through no- or low-cost solutions.

In response to recent changes in legislation, customer priorities and hardware, new software has been developed for monitoring and targeting. This software has been developed for, and in conjunction with, energy managers to provide solutions to the new challenges that face us in the 1990s and help organisations strive for greater efficiency.

Chapter 7
Modern Building Design Tools

This chapter describes modern design tools that can be used to assess the energy demands, lighting performance, aesthetics and other characteristics of a building as work progresses from pre-design planning through to final plans and specification. These design tools can also be used to assess the effects of retrofit or major building refurbishment proposals. The key feature of these design tools is their ability to handle large amounts of data and to integrate a wide range of building performance criteria. Consequently, they can play an important role in providing more energy efficient building designs. The need to increase the use and effectiveness of these tools and ways to improve the tools currently available are discussed.

7.1 Historic Development of Design Tools

As people have gained experience at building, they have tried to develop ways of passing their knowledge on so that future builders might benefit. Architects and engineers have created and used various types of design tools for the creation of buildings for centuries. Over time, these tools have grown from accumulated experience to empirical formulae to scientifically-based relationships and models. The tools have also become the shared knowledge for whole professional groups rather than the specialist knowledge, the "marketing edge", of one particular firm.

Today, architects and engineers have access to a wide range of practical tools. An engineer wishing to size a boiler in a particular climate, for example, has available a simple set of formulae based on an index of the coldness of the climate: the degree day and the 5th percentile coldest temperature.

Such empirical or rule-of-thumb design tools ignore many factors and were not likely to provide an optimal solution in each case. Experience generally indicated that the time and effort to get a better solution was not commensurate with the benefits, or that the tools to do a better job were just not available, or comprehensible to, most engineers. Since there was concern that in some cases the design tool might lead to under-performance, factors of safety were often increased, often with no real payoff but an increase in building cost.

The professional associations for both the architects and the engineers have been instrumental for much of this century in facilitating the development of design tools for their respective members. Some of these tools have crossed over from one group to the other. Typically, however, the tools have remained within the group for which they were devised.

Despite working on the same object — a building — the architect, HVAC engineer and lighting engineer all use very different language and values to judge the performance of that building. Yet it is clear that building form, and lighting and HVAC are interconnected (Chapter 2, 3, and 4 emphasise this point). Means to effectively integrate and reconcile the different aspects of building design are essential.

For the past 30 years, people with mathematics, physics and other scientific skills (and more recently computer knowledge) have formed teams to develop completely new design tools. These people often have links to engineering or architecture professional associations, but their principal task is not the design and construction of buildings, but rather to find out how buildings work and then to develop integrated design tools.

These science-oriented teams have typically been employed by national research laboratories and have been concerned to develop mathematical formulations of the physics of buildings. Thus they developed large computer programs that ran slowly on research laboratory computers in the late 1960s. During the 1970s these programs were refined and developed as the computing power became more readily available. During the 1980s the programs became more widely used outside the laboratory. Now, in places such as California there are many building design professionals who offer computer-based building performance analysis.

7.2 Dynamic Simulation versus Static Analysis

These new computer programs can mathematically simulate the thermal/visual performance of the building (hence they are collectively known as simulation programs). They can be used to study ideas and questions that have hitherto not been posed, either because there was no point, since adequate tools did not exist to address the question, or because thought provoking information generated by simulation was not previously available.

For example, with better thermal environment simulation programs, it is possible to accurately size the heating plant by considering the interrelationship with the heat storage and release properties of the building as well as its insulation properties. The difference between this approach and the traditional one is that the simulation program tries to model the dynamic behaviour of the building plus the plant under the dynamic influences of the climate and building occupants, while the traditional approach (illustrated by the boiler example mentioned earlier) uses a static calculation plus judgement and rules of thumb to allow for the dynamics.

As clients increasingly demand a higher and higher performance from their buildings, at lower and lower cost, building design professionals are under more pressure to reduce the size of the safety margins in their design — that is, avoid "overdesigned" plant or capacity. With dynamic simulations, the risk level in each design refinement can be more clearly identified. It is becoming routine, internationally, to use simulation programs in building design.

7.3 Issues for Simulation Tool Use

The use of simulation raises a number of important issues. Two of these issues are addressed here and illustrated by way of case studies:

- the level of data entry and programming and their costs; and
- what matters will be investigated and what type of output is needed?

The mathematical simulation of energy flows in buildings can range, for example, from the one-time calculation of the energy balance in the reflection, transmission and absorption of light, through the estimation of the dynamics of the absorption, storage, radiation, convection and conduction of heat. In each case, there is a minimum required amount of input data required to describe the physics. If simulation is to be adopted as a routine tool in building design, then data entry must be as simple as possible, and then be accessible to a range of different programs. There is also a need for programs that can either be easily upgraded to provide more detailed simulation, or a suite of ready-made programs that can be used at different stages in the design process.

The investigation of daylighting, natural ventilation and passive solar space heating for a regional police station illustrates these points. The challenge here was to develop a system of modelling that could quickly produce adequate answers early in the design process so that basic decisions could be taken or so that promising possibilities could be investigated further. This meant that the modelling had to initially cover representative parts of the proposed building in order to test design ideas. In this case, subsequent development of previous ideas, to a more complex level, required the complete rewriting of the input data file for the simulation.

With the simulation programs available today, it is often easier to begin writing a description of a new model than to develop a more sophisticated one on the basis of the old description. There is, as a result, much duplication of effort, and thus unnecessary cost, built into the process. This problem needs to be overcome to encourage greater use of simulation and hence obtain the energy efficiency benefits it can provide.

One of the most difficult issues facing the writer of the computer-based simulation program is deciding what questions the program is designed to "answer". Many programs are designed to produce accurate physical representations of the performance of the building. Simulation programs can do more, however, than just provide vast tables of data. Output can be quantitative data, such as light levels in lux, but could also be qualitative information, such as a picture showing what the building might look like given particular light sources — the sun, a cloudy sky, or an array of fluorescent lights.

Often, the qualitative information produced by a simulation will be most helpful if it can also be made quantitative. Building users or managers, an art curator for example, can apply their own experience to the qualitative information. The value of the qualitative data may also be increased by providing scales that users can relate to. For example, while examining the use of daylighting in a refurbishment of a building as an art gallery, it was found that daylight factor contours and numeric values of illuminance were unhelpful to the client and the designer. But equally, pictures of the space did not give enough quantitative information. What did prove of assistance was the introduction of a single spotlight illuminating a surface in the gallery to 150 lux. This gave the pictures produced at varying external light conditions their own built-in scale.

Simulation allows the use of time series data to provide risk analysis. The principal concern of the librarian during a simulation of a public library was the potential for overheating. It was not enough to present data showing that for a typical year, or even a range of years, the maximum temperature was acceptably low. What was required was an analysis of the frequency of occurrence of the high internal temperatures. In fact, for the level of confidence that this client sought with a natural ventilation cooling system what was really required was an analysis of the likelihood of high external temperatures occurring without the local sea breezes. Only when armed with an analysis of the frequency of occurrence of high temperatures based on multi-year weather data and with the coincidence data for high temperatures and wind was it possible to answer the concerns of the client.

People undertaking simulation gain experience with a project that can be used to provide reliable information without exhaustive investigation. In an office and studio development for a university, thermal and sunlight modelling was used to examine the likely performance of a central atrium/light well. In a four storey building of floor plan 3500 m^2, a 40 m^2 atrium can contribute a significant amount of light and heat. In this case, the ray-traced pictures provided some credibility to the analysis and the graphs of internal temperatures some reassurance that the analysis was rigorous. The architects sought further advice on the degree of change likely in the analysis with variations in the design.

As with all simulations of some rigour, each evaluation had taken a considerable time. Therefore, it was not possible to perform many simulations of a building this size and to provide a rigorous sensitivity analysis. What was most needed was information on the sensitivity of the output to changes in the input. Assuming enough runs have been done, the accumulated experience of the simulation team, familiar with the program and familiar with the type of simulation being done, will provide this information.

7.4 Coordination and Integration

For simulation to achieve its potential, more people need to be able to use the available design tools. A multidisciplinary team approach will be required, or at least the efficient exchange of information between experts. Integration, or improved interfaces, between simulation design tools will also be needed.

One or more experts need to be sitting at the shoulder of the person using the simulation program. These experts must ensure data from certain simulations (e.g. the lighting simulation) are available and consistent with the data entry requirements for other simulations (e.g. the heating energy simulation). Secondly, they must keep a record of the level of sophistication of the building model at each stage of the design process and maintain consistency between “versions”. Third, they must provide advice and even analysis on the interpretation of the many thousands of lines of data that the program can produce.

It is important to improve the exchange of information between members of the design team. If the data from the building design entered into the architect’s CAD program can be sent to the HVAC engineer’s building analysis program in an easy-to-read format, then the building industry will improve the quality and energy performance of the buildings it produces. Various information exchange standards (CAWS, CAD layering protocols) are being developed to facilitate this data exchange.

An alternative approach has been taken by one or two laboratories and computer program code writers: to develop more or less crude interfaces between two or three of the building simulation programs they know best. Two examples of this approach are the ADELINE suite of programs developed by the IEA Solar Heating and Cooling Programme and the “rad” interface between the thermal simulation program ESP-r and the lighting program RADIANCE. The primary limitation of this approach is that the whole design team has to use the suite of programs that has been integrated (several languages may have to be learnt).

Currently, there is no expertise in architects' offices in New Zealand to run thermal simulation programs. But many of the significant early design decisions about building materials, window size and orientation, and planning that can be evaluated with a simulation program are made by architects. The interaction between heat storage in the more massive elements of the building and the heating or cooling plant size is a complex question that requires changing of both building and plant. A case can be made for architects to have access to a tool that can provide basic information on the building form — HVAC plant trade-offs early in the design process.

The need to assist designers in the preliminary design phase was one of the motivating forces behind the development of ICAtect (Intelligent Computer-aided Architectural design assistant). ICAtect New Zealand is structured into three main parts: the common building model (CBM), the tool interface, and the user interface.

The common building model was designed to incorporate the information required by a set of simulation tools used at the Victoria University School of Architecture, mainly thermal and lighting tools, though structural and CAD tools were also considered. The common building model is an amalgamation of the objects, relationships and attributes found in these various design tools, integrated through data analysis of a similar nature to that employed in database schema integration.

ICAtect is structured for preliminary architectural design. To support this stage of design, it includes many defaults about properties of the building based on the building type. This means that the user has only to enter a minimal amount of information before an analysis may be performed.

To enable the information in the common building model to be used by the design tools and to garner the results of the design tools analysis, a tool interface mechanism was necessary. A two-step mechanism was used to force the mapping of information between tools and the CBM.

The user interface was designed in a similar manner to the mapping provided to one of the design tools, except that the user is dealing directly with the model of the CBM. This means the user has a single interface to all the design tools attached to the ICAtect system and only needs to learn one language to use the integrated design tools.

At this point, the ICAtect system is similar to other integrated systems being developed in the research community. For example, the COMBINE project is an EC initiative that is seen as a first step towards the development of 'intelligent integrated building design systems'. The AEDOT project is a USA led initiative that is examining integration in the scope of energy analysis tools.

7.5 Future Developments

Simulation programs now run on desktop or laptop computers. In fact, a relatively complex full-year simulation of the thermal performance of a building on a desktop 486 may only take three to four hours. Simulation technology is, therefore, readily available to motivated building design teams. With common office equipment and overnight runs, simulation programs can show the design team, including the client, many things about a proposed building, such as what the risk is of experiencing overheating in a sunny office or getting too cold at night in another office. They can show what it might look like in that office on a sunny or a cloudy day, complete with indications of glare.

The biggest problem for the near future will continue to be the integration problem. Integration not only of the design tools but also of the building design team will have to be resolved to enable energy efficiency to be addressed effectively.

If we look at the technology available today and speculate just how it might be used in future, it is not too far from the realms of possibility that the "artist's rendering" of the late 1990s will allow the client to experience, via VDU images or even virtual reality equipment, the lighting conditions in that favoured corner office under various external conditions: sunny, cloudy, night or early morning.

Certainly we can expect that the next ten years will see a major development in the use of expert systems to assist the design community to make the best use of simulation. Simulation programs are currently very good at producing tens of thousands of data points describing the performance of each element of the building (hour by hour values for every surface temperature, every heat flow, every litre of air leakage) Some are able to produce graphs to assist the assimilation of the bulk of data. But, to assist interpretation, more data analysis is required.

This is where the expert system, the accumulated knowledge of people intimately experienced with simulation, will be invaluable. Expert systems can help to ensure consistent and accurate input data, and they can provide insightful interpretation of the output data.

Chapter 8
Barriers, Codes and Standards

The marketplace — the commercial milieu of price signals, other information and incentives — does not effectively deliver energy efficient buildings. There are barriers at various points in the design and operation of commercial buildings that need to be addressed. Some of these barriers are similar to those present in the domestic building sector, and one of the remedies in that sector, the use of building codes, is likely to be applicable to commercial buildings as well. This chapter discusses the use of codes and standards to improve the energy performance of commercial buildings in New Zealand. It starts with an outline of some of the barriers to energy efficient buildings.

8.1 Barriers to Efficiency

A major barrier arises from the different interests of the stakeholders in a building. The nation has an interest in energy efficiency for various reasons, including investigation of climate change, but at the moment this interest is not communicated to the other stakeholders in a strong enough manner. Current policies, such as voluntary agreements on emission reductions, are mainly targeted at industrial users of energy. EECA has a number of programmes, however, to facilitate better awareness of energy efficiency opportunities in commercial buildings. These programmes have to overcome the lack of incentives for other stakeholders.

The incentives for the commercial building developer are to produce a product that costs as little as possible in terms of design fees and capital, while still meeting the needs of potential buyers. Unless the likely buyers are interested in future energy costs, the developer is not likely to place much priority on energy efficiency unless it leads to lower capital costs, which it can do (efficient lighting means less HVAC). Even if the buyer is interested in energy efficiency, there is no simple measure of building performance by which they could decide on the merits of a building.

The buyer may let the building space in such a way that operating costs are passed on to occupants. Whether the owner or occupiers meets the energy costs, they will not have a strong incentive to deal with energy efficiency compared to other building operating costs; only around 2% of the total running costs are energy related. Finally, while individual building occupants make decisions every day about how energy is to be used they have no influence on the building design.

The current trend toward fixed price fees for design consultants rather than fees based on the amount of equipment that was installed has mitigated one problem. Consultants are no longer rewarded for specifying equipment, such as large HVAC systems, when careful design could have reduced loads. However, this trend also creates an incentive to minimise design time. Basic formulaic installation of the simplest systems results. The opportunities to do life-cycle costings of fuel, technology or design options are not fully realised. In a simple aphorism, minimum fee equals minimum design, or less (cost now) is more (cost later).

Annual prize ceremonies and the more influential writings of the architectural profession reveal that there is little professional encouragement for energy efficient design. Despite the considerable efforts of some people and the interest apparent amongst the majority of architects, the economic and professional rewards for innovation or achievement in this area are small.

Providing information and encouragement, as EECA is doing, is one way to address the barriers. Another option is to use energy taxes (or use another economic instrument with the same effect) so that energy costs make up more than 2% of a building owner's outgoings and, consequently, attracted more attention. It has been suggested that requiring the price of energy to include the full cost of production (pollution cleanup, greenhouse gas limitation, etc.) would raise the price in this way.

Steps could be taken to further improve the market information; for example, the sector could arrive at a consensus on an energy performance target — possibly representing best current practice — which everyone recognised as a valid means of comparing one building with another. This could become a marketing factor for a building. Sections 8.2 and 8.3 discuss the application of mandatory standards for commercial building energy efficiency. Standards can take many forms, from mandatory specifications of materials and forms of construction to single figure performance targets.

Voluntary targets or codes can provide some of the benefits of mandatory standards. As has been pointed out in Australia recently (Round Table, 1993), voluntary codes become mandatory in all but name as they gain acceptance by the community. As soon as it becomes widely acceptable to publish a uniform minimum specification in a leasing agreement or design brief, then it might just as well be mandatory. Having a mandatory standard does, however, accelerate compliance and deal with recalcitrant parties.

8.2 New Zealand Situation

The introduction of the Building Code in 1993 has defined a clear role for measures related to health, safety and energy efficiency in New Zealand buildings. The Code, which is managed by the Building Industry Authority (BIA), sets out in Clause H1, the Objective, the Functional Requirement and the Performance Requirement necessary to facilitate the efficient use of energy in new buildings. Clause H1 is reproduced in Box 8.1. At present, the performance requirement only applies to housing not commercial buildings.

At the operational level, the NZBC is supported by an Approved Document, published by the BIA, which sets out means of meeting the requirements of the Clause (Acceptable Solutions) and of verifying that any proposed new building will meet the Code's objectives (Verification Methods). Acceptable Solutions are based on standards published by the New Zealand Standards Authority. A system of certification of people to approve other solutions as meeting the legislated performance is in place. However, what has yet to be fully worked through is a suite of performance requirements and means of compliance for commercial buildings.

The NZBC Clause H1 only notes those aspects of energy use that should be considered when a commercial building is being designed (see Clause H1.3.2 in Box 8.1). The energy focus is on space heating and cooling. The intention of the Clause H1 is that energy use should receive the same attention as any other aspect of design, such as structural stability or weatherproofing; there is no hierarchy of performance. The effectiveness of the provision is based firstly on the idea that a thorough approach to these issues will be of long-term benefit to the building owner (an incentive) and secondly that in order to demonstrate that these issues have been considered, the applicant for a building consent should supply the Territorial Authority with considerable documentation.

At present, there is no consensus between Territorial Authorities as to what constitutes an acceptable standard of documentation. In addition, most do not have the in-house expertise to evaluate it if it was presented to them.

While New Zealand does not have a mandatory, quantified energy efficiency performance standard for commercial buildings, a set of benchmarks or targets have been identified for different energy services in commercial buildings. As mentioned in Chapter 1, New Zealand standard NZS4220 provides targets based on surveys conducted during the late 1970s and early 1980s into the actual energy consumption in a large number of commercial buildings throughout New Zealand. The purpose of NZ4220 was to provide better information to the various parties involved in commercial building design, construction, ownership and management. While targets are useful, there is still not much incentive to seriously use them; they only address one of the barriers mentioned in Section 8.1.

It can be argued that the present situation is not adequately addressing the barriers to energy efficient commercial buildings. This appears to have been recognised. In June 1993, the Minister of Energy announced that, as part of its Climate Change Strategy, the Government would provide additional funding for EECA to collaborate with the BIA on the development of improved/updated energy efficiency requirements for commercial and residential buildings.

A process of review has been established (EECA, 1994). A workshop was held in October 1993 and another in June 1994. A discussion paper was published in August 1994. The work programme aims to finalise the revisions to Clause H1 by the end of 1995. The new supporting documents would be available to the sector

Box 8.1: NZBC Clause H1 Energy Efficiency

This Clause is extracted from the New Zealand Building Code contained in the First Schedule of the Building Regulations 1992.

Provisions	Limits on application
OBJECTIVE	
H1.1 The objective of this provision is to facilitate efficient use of energy.	
FUNCTIONAL REQUIREMENT	
H1.2 *Buildings*, throughout their lives, shall have provision for ensuring efficient energy use in controlling indoor temperature when that energy is sourced from a public electricity supply, or any other depletable energy resource.	
PERFORMANCE	
H1.3.1 The *building* envelope shall be *constructed* to ensure that the *building performance index* shall not exceed 0.13 kWh.	Performance H1.3.1 applies only to *Housing*.
H1.3.2 Where any space within a *building* is intended to have a controlled temperature, *construction* of *building elements* affecting energy use shall take account of: (a) Thermal resistance to heat loss through the *building* envelope, (b) Heat gains (including solar radiation) through the building envelope, (c) Airtightness, (d) The contribution to space heating of heat losses from *building* services (including hot water systems, and lighting), (e) Control systems for heating and ventilating, and for other services, and (f) Utilisation of waste heat from internal processes.	Performance H1.3.2 shall not apply to *Housing, Outbuildings, Ancillary buildings*, or *buildings* with a floor area of less than 50 m^2.

for comment in October/November 1995 and finalised and published by April 1996. It is expected that the new provisions would be in force by October 1996. Some of the issues that are being addressed in the review are discussed in Section 8.5 below. Meanwhile, it is useful to examine whether the targets in NZ4220 could form a basis for future mandatory and quantified standards and to outline overseas approaches to standards.

The figures in NZS4220 differentiate between different occupancies or uses of buildings. A place of assembly or a commercial residential building, such as a hotel, have very different performance specifications than a standard office building. This creates a difficulty in that buildings change use during their lifetime. Arguably it also creates a slight incentive for designers to try to place their building in a use class that is permitted to have high energy demands. In the USA, building authorities appear to have backed away from building-use based targets in favour of a single figure (or set of figures for different energy services) that covers a wide range of commercial buildings. A single figure is also easier for the approving Territorial Authority to deal with.

The number of use classes in NZ4220 may need to be reduced, but the figures also require updating before they could form the basis of mandatory standards. New targets are needed to account for changes in the energy use associated with the processes that now go on in commercial buildings (e.g. use of office equipment). Changes in process energy can also feed back into changes in HVAC and further affect the overall building energy use. The need to review the data only ten years after it was first generated indicates that the performance targets will probably require five to ten year updating to account for changes in office automation and equipment efficiencies.

Another issue that will need to be resolved is whether or not a set of figures for different energy services should be retained, or if the focus should be on a single, total energy standard for a building. Single-figure specifications have their difficulties. Some places, such as California, have specifically decided not to allow the types of trade-off implicit in a single-figure specification of performance. Authorities there did not, for example, want designers to save energy by installing solar domestic hot water heating in order to make up for the waste of heat through poor wall insulation.

8.3 Overseas Building Standards

There are many international precedents for energy performance requirements at code or standard level. Many were first introduced during the 1970s following the first major oil shock. France and Japan, for example, introduced specific measures to limit energy use as they were particularly dependent, at that time, on imported oil for electricity generation. The regulations or codes have subsequently changed markedly as better understanding of buildings and their energy systems has developed.

The USA has three different not-for-profit organisations that write energy performance standards, which are implemented to varying degrees by state governments. To date, California's Title 24 code requirements and the Association for Heating Refrigeration and Airconditioning Engineers (ASHRAE) 90.1 Standard have received the most exposure in New Zealand.

Canada has a mandatory and fairly comprehensive commercial building code, which it is currently in the process of reviewing. Germany and Japan have codes that include consideration of environmental issues beyond those of the simple examination of nonrenewable energy resource utilisation.

The Scandinavian countries, Sweden, Denmark and Norway, have long had energy performance requirements for buildings. These take different forms and have a different *raison d'etre* in each individual country. In Norway, an abundance of hydroelectricity ensures that the government's goals for the energy performance requirements are significantly at variance to those in Sweden, which has a mandated requirement to reduce reliance on nuclear-generated electricity, or to those in Denmark, which has milder winters and less hydroelectricity.

In the UK, the Building Regulations, which are undergoing a review, contain a section that has energy conservation as its objective. The regulations go beyond merely setting a goal of efficiency of energy use and assuming conservation or reduction in consumption will follow. The UK system has an approved document as a means of compliance.

While the public administrative philosophies and government systems are different, the development of commercial building energy performance codes and standards in Australia is relevant to New Zealand. The rigorous approach to the development of the standards in Australia contains much that is worth adopting in New Zealand. The development is based on a life-cycle cost-benefit analysis of energy efficiency measures, including both equipment, such as lighting, and the building fabric, such as types of glazing.

The overriding view in Australia is that energy efficiency measures must have favourable financial implications for the owner/occupiers (Australian Discussion Document, 1994) . In this, they reflect the approach of the ASHRAE standards.

A further tier of analysis is adopted in the Commercial Building Energy Code study in Australia. Having determined a measure is cost-effective to the building owner, the code analysts then examine the benefits to the state or country as a whole. National benefits are estimated on the basis of deferred power generation, carbon dioxide emission reductions and other public goods. This is useful in that it helps to place the public administration costs of a building code system in perspective.

8.4 Issues for Commercial Building Standards

This section discusses a number of issues that need to be resolved in formulating commercial building energy efficiency standards. There are two basic approaches to setting such standards:

- performance standards — establish a set of overall targets, either a single figure for the whole building or a set of figures for energy services, that must achieved for a particular building; and
- prescriptive standards — prescribe a particular dimension, ratio or other physical parameter for the components of a building, e.g. windows must constitute no more than 30% of the wall facade.

Performance standards specify either the required performance of a number of key components of a building, or set one performance level for the energy performance of the whole building. The latter is presumed to allow the greater freedom in design, as it allows the architect to add design features not previously thought of which perhaps through some small energy cost in one area, achieve a major energy saving in another. The specification of the performance of components places emphasis on the component or product rather than the designer assembling the pieces. Thus a minimum window performance standard allows window manufacturers to compete, but no-one makes any connection between their efforts and the role of glazing, and those of the competing manufacturers of airconditioning.

Prescribing the size, shape or materials of the components of a building is conventionally described as a prescriptive standard for energy efficiency. In the context of the BIA and the NZBC philosophy, a prescription of this type could only be afforded the status of a means of compliance (Acceptable Solution) with the performance specified in the building code itself. All countries that produce energy efficiency standards make allowance through prescriptive options for the speculator or formula builder who wishes to do as little new analysis as possible. Basically, they state, if you are prepared to accept this formula for building, then your building is deemed to comply with the energy efficiency requirements of the code.

As well as the type of standard, there is a range of other issues relating to the scope of standards. These are outlined below.

Building Type and Size

An obvious definition problem is determination of what is a “commercial” or “non-domestic” building. While apparently trivial, this cuts to the heart of the energy efficiency debate, because the energy performance differences between “shops”, “offices”, “schools”, “gymnasiums” and so on are as much due to the equipment and processes they house as they are to different building types or constructions. For example, in defining energy performance standards for a restaurant, should one include the kitchen energy use? It is an integral part of the heating and cooling of the whole restaurant, if only because often a large part of the ventilation air for the cookers is drawn through the restaurant! In the context of the energy efficiency definitions of the NZBC, this question becomes even more difficult to answer.

One way through this issue is to differentiate buildings on the basis of their size. In deep plan office type buildings, the heat generated in the core is more than is needed to heat the whole building for much of the year (this building type was referred to in Chapter 1 as internal load dominated — ILD). Thus the building needs to lose as much heat as possible throughout a good part of the year and will usually have a HVAC system. Less insulation, not more, is often part of the cooling strategy (however, there may be a number of other reasons to do with draughts, thermal comfort and overall energy conservation why double glazing and thermal insulation are sensible choices in some cases).

Small commercial buildings (skin load dominated — SLD), on the other hand, will mostly need space heat, generally provided by simple appliances rather than HVAC systems, and they will also benefit from good insulation. As space conditioning requirements can be linked to the type of building construction, which is roughly related to size, a differentiation on floor area may be sensible. All large buildings, irrespective of occupancy, could have one space conditioning target, while small commercial buildings could have another.

Targets and Priorities

The issue of a single building target versus a set of targets for the different energy services was discussed earlier. There are advantages in having a set of targets for the energy services that can be easily differentiated — lighting, water heating and space conditioning. While these services may be linked in one sense, they often draw on different fuel sources. This is particularly true of lighting, which invariably comes from electricity (other than from daylighting).

Arguably, lighting energy use is the most important single energy use in a building dominated by internal loads (ILD). It is important to understand why. First, it is more important than heating energy use because typically it is provided by a more expensive heating fuel — electricity. Thus while lighting may be only 30% of the energy use compared with the heating energy use (40% to 50%), when the energy costs are calculated, lighting reaches 40% to 60% of the total costs compared with 30% to 40% for heating energy cost. If one adds to this calculation the "contribution" that lighting makes to the increased need for cooling, then lighting and lighting design is indeed a major cause for concern.

Old Versus New Buildings

Section 6 of the Building Act identifies new buildings as the only ones subject to the Act's control through the Building Code. As a consequence, any Code innovations would take considerable time to have significant impact on a national basis. As part of any study of the energy performance provisions of the Building Code, such as is planned for the next two years, there is a need to conduct a study into the likely changes in the building stock over the next decade of operation of the Code. Non-domestic building energy performance can be significantly affected by upgrading and retrofitting both the fabric and the energy consuming systems of existing buildings.

The question to be resolved is whether there should be some requirement on retrofits and upgrades to follow the Building Code requirements or whether to assume that the Code will provide guidance that will be taken up by an informed market. When it applies to both new and retrofitted buildings, then a Code has the potential for far-reaching effects on the energy efficiency of the nation as a whole.

Ease of Implementation

A fundamental issue is developing standards that are easy to understanding and implement. The most sophisticated of performance specifications will achieve little if they cannot be supported by the industry it attempts to regulate because it is too complex for all but a few experts to use. It will also have little long-term effect if it produces performance specifications that the market cannot comprehend or place a value on. Everyone has a basic understanding of the relative value of the fuel economy figures of their own car; few, if any, can say the same about the energy economy figures for their building.

Embodied Energy

In the creation of building energy efficiency standards, an important issue is the energy required to manufacture building materials and equipment. A similar issue arises with respect to retrofitting energy efficiency equipment. The question is whether the additional energy investment to produce a new energy saving device/component is actually less than the energy saved by the device during its operational lifetime. Recent work at Victoria University (Treleavan, 1993) suggests that in energy terms, efficiency devices easily pay for themselves.

While energy analysis of individual retrofit items may be feasible, knowledge limitations mean that it will be difficult, for the time being, to calculate the embodied energy in buildings. It will be even more difficult to optimise (via trade-offs) the sum of embodied energy and operational energy requirements for a commercial building.

8.5 Performance Assessment and Implementation

At the simplest level, the specification of a standard or a means of compliance with a building energy performance code that prescribes the actual sizes and proportions of building components seems uncomplicated and readily written. However, if this standard building specification is to be justified with economic analyses (for the owner and for the community), then it is likely to be the subject of the most exhaustive research investigation of any part of a code.

The complication arises from examination of all the possible design combinations that might reduce energy use in order to identify the optimum. It is likely that the only building standard of this type that will be acceptable will in fact be a specification of a range of acceptable solutions rather than just one design.

California Title 24 and ASHRAE/IES 90.1 have system performance methods for the envelope and lighting systems. Essentially, these calculation methods allow a standard index of system performance to be calculated. Various aids are provided to assist the calculation. Computer programs calculate figures of merit that can be compared against tables in the standard. For example, in California, the building must meet both a heat gain and a heat loss figure of merit. For the heat loss calculation, the U-value of each part of the building is multiplied by its area and then all figures are summed. The result must be less than that for a pre-defined "standard" design.

It is clear that the calculation methods used internationally are simply adapted and could be readily applied in New Zealand. They are all sufficiently complex, however, that a major training programme would be needed prior to their widespread introduction. What is not clear is the amount of work that would be required to establish the appropriate local figures of merit for the standard design(s) that would provide the means of measuring or assessing performance. Certainly, this figure of merit will require exhaustive testing for its economic assessment and justification from the building owners' or the national viewpoint.

If the system performance specification approach is to be adopted, then there is one area in which much further work needs to be done: the creation of a means of calculating the performance of the HVAC systems. At present, there appears to be no such performance evaluation system available anywhere.

In some ways, the simplest form of assessment method to establish in New Zealand is the whole building performance method. Precedents exist in various international standards. The computer simulation programs typically used to perform the analyses are becoming more widely used. There are even local practitioners expert in their use, and data files specific to New Zealand weather and construction have been developed (van der Werff et. al., 1990).

What will require development in New Zealand is establishment of the local veracity of the assumptions inherent in the creation of these programs. For example, it is conventional in daylighting programs to assume a certain international standard luminance (brightness) distribution for the sky. This is based on measurements for skies in locations typically in continental climates. Work currently being undertaken by Industrial Research Limited with the Foundation for Research, Science and Technology is addressing this particular issue.

While the simplest to introduce, the whole building performance assessment method is the most difficult to implement. This is the case in all countries where the approach has been attempted. The basic problem is that of specifying the required input data in an unambiguous manner, specifying the performance itself in an equally clear manner and establishing a system of certification of the people to do the assessments and of the computer programs to do them. This latter is important if this system is to achieve more than the banality of a check of a single figure of merit by the Territorial Authority official checking the documentation of many hours of complex simulation of the real performance of the building.

The final question that must be addressed in the establishment of energy codes and standards of more sophistication in New Zealand will centre on training. Code officials in Territorial Authorities must receive training in the interpretation and enforcement of the code requirements. However, the various players in the design and construction team must also gain a much more detailed understanding of the importance of their actions.

It is likely that buildings will eventually become more sophisticated in order to be more responsive to climate and energy requirements. Users will need to be better informed to be able to exploit this. In addition, users as the ultimate customers of the design team will have to become better informed as to what is acceptable and what is unacceptable building energy performance. Only then can the supposed benefits of codes and standards become influential in providing the marketplace structure referred to at the beginning of this chapter.

References

Australian Discussion Document (1994). *Code Structure Issues Analysis*, draft for discussion produced for the Australian Commercial Building Code, 1994.

EECA (1994). *Energy Efficiency Building Standards Project — Discussion Paper*, Wellington.

Round Table (1993). *Round Table on Commercial Building Energy Code exercise*, Canberra, August 1993.

Treleaven, C (1993). Research report for Dip Env Studies, Victoria University of Wellington.

van der Werff, I, M Donn and R Amor (1990). *Standard Data Files for Computer Thermal Simulation of Solar Non-residential Buildings*, ERG Report CRP 53.

Chapter 9
Commercial and Institutional Buildings — Case Studies

9.1 Introduction

This section provides a brief description of a number of cases where energy efficiency has been improved in commercial and institutional buildings. Many more very good examples could be added to those presented below. The cases chosen cover a university and a school, a hotel and a hostel, a shopping centre, a utilities building (telephone exchange), two libraries and an office building. These examples represent a good cross-section of commercial and institutional buildings and provide an indication of the potential to achieve energy efficiency in commercial buildings at design and build, operational and retrofit stages.

The Nelson City Library case study (Section 9.2) emphasises the importance of careful energy modelling at the design stage and the use and control of sunlight and natural ventilation. The National Library case study (Section 9.3) demonstrates that, even in a relatively modern building, there are many opportunities for energy efficiency that await an enthusiastic building manager. The key is a comprehensive energy management programme, systematically pursued.

The National Mutual Building in Wellington (Section 9.4) is an example of how a major lighting and airconditioning upgrade can save energy, reduce operating costs, improve the working environment and contribute to the letting potential of a building. The Old Kirk Building at Victoria University (Section 9.5) was refurbished with an emphasis on energy efficiency throughout. Insulation, draft-proofing, improved heating, zoned ventilation and efficient lighting were used to bring this building, once under threat of demolition, up to modern standards.

The St Lukes Shopping Centre, Mt Albert, Auckland (Section 9.6), was refurbished to yield 70% more lettable floor area and an improved shopping and working environment, with a fall in energy use per trading hour. The key to this success was greater use of natural light, an increase in the number of lighting zones, well-controlled airconditioning and good plant selection.

The Quality Hotel in Palmerston North (Section 9.7) presents another commercial success story. With expansion, occupancy increased by just over 20%, but energy use fell by nearly 4%. This was achieved through a lighting upgrade and the use of a key tag system to activate guest room energy services. The changes have made staff and management more aware of energy efficiency and have drawn positive responses from guests.

The design and construction of the KingsWay School at Orewa (Section 9.8) is a triumph for all concerned — architects, voluntary labour, staff and students. A unique learning environment has been created with an energy performance well ahead of expectations. The school shows that, with creativity, a range of design and construction constraints can be addressed without compromising energy efficiency.

The new Telecom Central Exchange in Christchurch (Section 9.9) demonstrates how the effective management of heat gain problems can save money and energy. Solar gain has been minimised and maximum use is made of cool outside air when it is available. This, combined with efficient lighting and a localised variable volume, variable temperature airconditioning system, means that plant and occupant requirements are efficiently met.

While energy use for hot water supplies is only significant for hospitals, residential institutions and hotels/motels, this does not mean it should be overlooked. A variety of technologies are available to improve hot water energy efficiency. Many of these, such as low-flow shower heads, are also applicable to domestic housing situations. Some, however, are more applicable to larger buildings. One of these, the Platypus water management system, is described in Section 9.10.

9.2 Nelson City Library

The Nelson City Library is an excellent example of the benefits of design assistance and was the winner of a Beta Award [1] in 1992. Daylighting and thermal performance analysis were undertaken at the design stage and energy and environmental performance was subsequently monitored during the first year of occupancy under the demonstration programme operated by EECA.

Energy modelling and related work added $24,000 to design costs but reduced the total project cost by 5% ($70,000) and yielded operating cost savings of $8400 per annum. This was achieved by a thermal performance analysis, which concluded that a $50,000 airconditioning plant was not required. The resulting reduction in electrical load provided a further $20,000 capital saving as a new substation was not required. In summary, energy efficient features used in the building include:

- the extensive use of clerestory windows to provide daylight throughout the building without night sky heat loss;
- external shades for high summer sun that double as reflectors to enhance daylighting deep in the building;
- a central courtyard to let natural light and fresh air deep into the building as well as providing an attractive focus for all users;
- electrically-operated, high-level windows and manually-operated, wall-mounted, low-level louvres for controlled and effective natural ventilation of a deep-plan building;
- electric ceiling fans to provide air movement and fresh air distribution throughout the entire building;
- higher levels of thermal insulation than would be normal in a commercial building; and
- ceiling-mounted radiant heating panels under optimiser control in the public areas and nightstore heaters in offices.

Daylight is the main light source for three-quarters of the working day across 25% of the public areas.

The energy intensity of the library is about 40% of the norm for commercial buildings of this type. The energy intensity also compares favourably with both New Zealand and overseas targets (see Table 9.1).

	MJ/m^2/yr
Nelson City Library (actual energy use)	180
Target for new commercial buildings (NZS4220:1982)[1]	414
Building Energy Performance Target[2]	300
Energy Efficiency Office UK — Good performance for libraries[3]	<720

Notes:

1. Target expressed in terms of net rentable area.
2. Building energy performance targets 1989. Prepared for Works and Development Services Corporation (NZ) Ltd by the School of Architecture, Victoria University of Wellington.
3. Energy audits and surveys, 1991. Chartered Institution of Building Services Engineers applications manual.

Table 9.1: Comparison of Nelson City Library energy intensity with various building targets

9.3 The National Library, Wellington

The National Library building in Wellington provides an example of the benefits of a comprehensive energy management programme in a relatively new building. The Manager of Property Resources has systematically identified opportunities to reduce energy use.

Over the past five years, electricity consumption in the National Library building has been cut by 46%. The National Library also occupies the basement of the adjacent State Services Commission building. Energy management initiatives for this basement area have resulted in a 39% electricity saving over the same five year period.

In a number of areas, lighting energy has been halved by delamping to achieve illumination levels appropriate to each space. All light fittings have been labelled to assist maintenance staff to correctly relamp each fitting. Mirror reflectors and triphosphor tubes have been used to improve lighting efficiency. Banks of light switches have been labelled to indicate the areas they serve and, in bookstack areas, timer switches have been retrofitted so that lights are not left on when spaces are unoccupied.

Motor loadings on the all the main ventilation plants have been checked and in many cases motors have been downsized dramatically without any effect on ventilation rates. The motor for the main fresh air fan was downsized from 30 kW to 7 kW. In the loading bay area, where natural ventilation is adequate, the mechanical ventilation system has been decommissioned.

Modifications to the refrigeration plants that serve controlled environment spaces have eliminated the need to operate the main chillers at night. Heat from refrigeration units is rejected into the condenser water system rather than the chilled water system. This has meant the main chillers can be switched off at night and the heat is rejected from the cooling tower. Interconnection of previously-independent chiller systems has enabled the chiller capacity to be more closely matched to the chilled water load. This ensures that each chiller unit operates at optimum efficiency. When the outside air temperature drops below 11˚C, the chillers are switched off and outside air is used to provide cooling.

The building has been disconnected from a district heating system centred in the Freyberg Building. Hot water was previously supplied to the library at 110˚C. The library's heating requirements are now met with standalone boilers that operate at 80˚C.

A computer-based building management system provides remote monitoring and fingertip control of all major mechanical plants. The system provides instantaneous information for maintenance and energy management. Other buildings in Palmerston North, Auckland and Christchurch are being linked into the system by modem/ telephone communication.

The building's maximum electrical demand has been reduced by improving the power factor, which was achieved by installing capacitors on the main switchboard. The result has been a significant reduction in maximum demand charges.

Since the building was first occupied, about 500 personal computers have been installed, together with numerous printers and photocopiers. The Manager of Property Resources uses an innovative management technique to make sure unnecessary equipment is switched off after hours. Security guards make frequent checks to note any office equipment left operating. Each month, the various departments are billed for the energy costs of the unoccupied equipment and the revenue collected is credited to the building manager's budget to cover additional electricity charges.

9.4 The National Mutual Building, Wellington

The National Mutual Building at 70 the Terrace, Wellington, won a Beta Merit Award in 1994 for a refurbishment that upgraded the lifts, airconditioning and lighting. Originally completed in 1973, the building was designed by its owner-occupier, National Airlines Corporation, to a relatively high structural and mechanical standard, but not necessarily with energy efficiency in mind. Subsequently, the building became the National Mutual head office. Following the move of National Mutual into a new Head Office building in 1990, 70 the Terrace was effectively left vacant and it was clear that a major refurbishment was needed to restore the commercial viability of the building in an over-supplied market.

An assessment of the building revealed shortcomings with respect to its working environment — acoustic conditions, lighting, thermal environment, temperature, humidity and air quality. The refurbishment concentrated on improving these aspects and in so doing made significant improvements in energy efficiency.

The lighting retrofit, independently monitored by EECA [2], involved replacement of two-tube fittings with single-tube fittings containing a mirror reflector (3M Silverlux™ silver mirror reflectors), low cost ballasts (ATCO) and high efficiency triphosphor tubes (Philips 84). The 3M reflectors used have excellent long-life reflective properties (see Box 9.1). The number of tubes per floor was reduced by 60%, from 296 to 120, and the power demand was consequently reduced by 65%, from 14.5 kW to 5.1 kW. Lighting efficiency (defined as service illuminance per unit of lighting load) has increased by 165%. The service illuminance of 535 lux has been achieved for a lighting load of 11 W/m^2.

Box 9.1: The 3M Silverlux™ Silver Mirror Reflectors

3M Silverlux™ silver mirror reflectors have a specular reflectivity of 95% (97% total reflectivity) and are made from the most reflective material known. This performance, combined with the optically-designed profile, maximised the output of the light fittings.

3M Silverlux™ reflectors are composed of a front-reflective film constructed of a pure silver-coated self-adhesive polyester film laminated to chromate-treated aluminium. A protective double layer of acrylic with UV absorbers covers the silver. These layers are designed to protect the silver from mechanical damage and oxidation, and also protect the polyester and adhesive from degrading due to ultraviolet light. An adhesive is applied to the back of the base for attachment to the backing surfaces. Figure 9.1 shows the difference between front and rear reflective films.

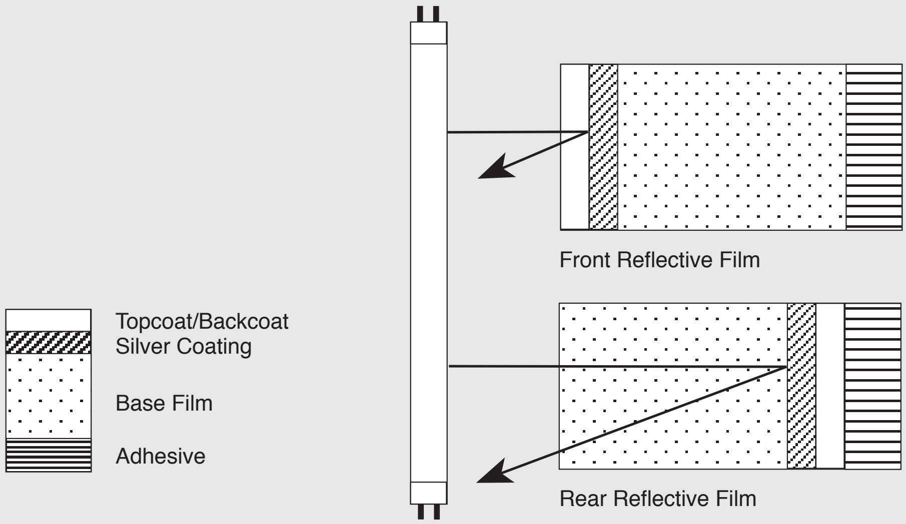


Figure 9.1: M Silverlux™ reflector structure

Good lighting design allows for depreciation of tubes and reflective surfaces. 3M claim Silverlux™ reflectors will continue to provide optimum performance year after year.

Due to the front-silvered film construction, the reflector suffers almost no deterioration from the ultraviolet present in fluorescent fittings. The product uses a patented silver corrosion inhibitor to prevent oxidation, even if the protective coating is scratched. 3M have carried out accelerated ageing tests on UV degradation that indicate that there is only a 1% loss in reflectance after exposure equivalent to eight years (2600 hours per year) of normal office operation.

Figure 9. 2 shows results from accelerated ageing tests for various types of reflectors. The results show that silver reflectors are superior to all other reflectors, including white paint and polished aluminium. 3M claim a life expectancy in excess of 15 years. The product is offered with a five-year warranty against defects in the material in New Zealand.

Reflectors can deteriorate in performance due to dirt buildup. Tests in offices indicate that 3M Silverlux™ reflectors lose less than 3% of their reflectivity over a four-year period. After cleaning, all tested reflectors returned to 99% of their original reflectivity.

The specular (mirror quality) reflectivity of 95% of the Silverlux™ reflectors compared to the diffuse (light but rough surface) reflectivity of standard painted troffer boxes of around 80% to 85% when new, combined with superior optical design, provides much of the lighting efficiency gains.

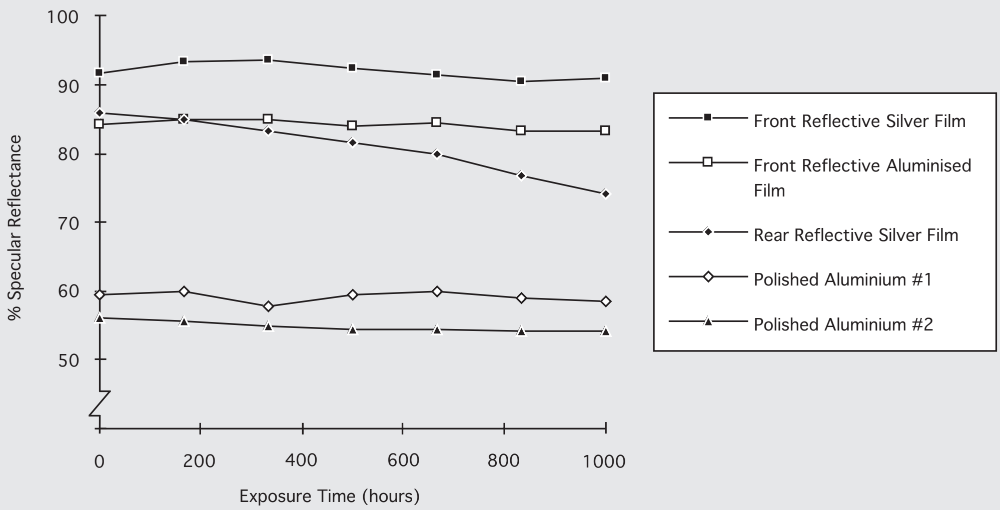


Figure 9.2: Fluorescent lamp reflective ageing comparison

The marginal cost of the chosen retrofit was $35,000 compared to a standard lighting retrofit. Total annual electrical energy savings are about 375,000 kWh. Net operating cost savings, allowing for summer airconditioning savings, increased winter heating costs and reduced lamp replacement costs, are $48,000 per annum. Although not independently monitored, automatic light switching controls, consisting of movement detectors, door switches and multi-channel time clocks, are estimated to save an additional 15% of total lighting energy.

The new system has dramatically improved the colour of the lighting and the use of specular mirror reflectors has markedly reduced the lighting glare — lighting is now very comfortable throughout the building. Lighting uniformity is high, as the number of light sources (fittings) has not been reduced. The new occupants of the National Mutual building are very satisfied with the lighting, so it appears that the upgrade has enhanced the commercial value of the building from a letting perspective.

Conversion of the airconditioning system from a constant-volume central-zone to variable air volume system has minimised the need for wasteful terminal reheating. The old pneumatic controls have been converted to a direct digital control system coupled to a computer-based building management system. These changes have resulted in a 15% saving in airconditioning energy needs. The new system has achieved stable and comfortable temperatures, close control of humidity and frequent controlled air changes. The feel and freshness of the building has improved from the old, slightly stuffy and noisy environment.

The existing 20-year old Otis lift installation was upgraded with the Otis Elvonic 401 package, which incorporates an array of technical innovations, including a microprocessor control system, which significantly improves passenger comfort, reduces waiting time and saves up to 30% on energy.

Figure 9.3: Facade of the National Mutual building, Wellington (photo courtesy of Energy Management Ltd, Wellington)

Figure 9.4: 3M Silverlux reflectors used in the retrofit of the National Mutual building, Wellington (photo courtesy of Energy Management Ltd, Wellington)

9.5 Victoria University of Wellington

Since the mid 1980s, Victoria University has implemented a number of energy management projects. The programme is ongoing and has continued to improve the energy efficiency of the campus and to lower its costs. Two buildings in which significant improvements in energy efficiency have been achieved are the Rankine Brown Library and the Old Kirk building.

Rankine Brown Library

Three separate types of lighting improvements have been made to the library, which have reduced lighting energy consumption by 65% (worth about $16,000 a year) for an outlay of $42,000.

Single-tube fittings with reflectors have replaced double-tube fittings, giving higher light levels and doubling the efficiency of the original lighting. In addition, the 50% reduction in tubes has lowered maintenance costs.

The 100-watt incandescent bulbs for staircase lighting have been replaced by 9-watt miniature fluorescent lamps, which last eight times as long. The longer life of the replacement lamps has reduced maintenance costs and improved safety by reducing the frequency of lamp failures.

Book stack lighting was originally controlled by local pull cords. In practice, most of the lighting remained on during opening hours although most of the book stacks were unoccupied at any one time. The pull cords were replaced with push button timer switches to switch off the lights after a ten minute delay. This has reduced overall energy use for the book stack lighting by about 90%.

Old Kirk Building

The Old Kirk building won a national Beta award in 1993 for a major refurbishment with an emphasis on energy efficiency throughout.

The previously uninsulated roof space was fitted with R3.4 fibreglass batts, and air infiltration was reduced by fitting new window hinges and latches. The original heating system consisted of aged perimeter electric convectors, which were replaced by a combination of heat pumps, nightstore heaters and ceiling fans.

The building has a 4 m stud, which, on occasion, resulted in thermal stratification of over 4˚C between floor and ceiling. Ceiling fans were installed in workrooms and libraries to reduce this temperature difference and provide comfort at a lower average room temperature. Each 60-watt fan displaced the need for about 1 kW of extra heating capacity. The fans are also used on higher speed during summer to provide cooling.

An airconditioning unit that used ozone-depleting R12 was removed. The evaporative cooling tower that served the unit used large quantities of water and required regular maintenance. To reduce the need for extensive airconditioning in the refurbishment, exhaust ventilation was installed to remove internal heat gains from copy rooms and kitchens. A staff seminar room and a secretaries' room with cooling demands have been provided with local split-system air conditioners and a fresh air supply.

The original lighting consisted of a mixture of ceiling-mounted switch-start and quick-start twin-tube fittings using 38 mm tubes. These have been replaced by suspended single-tube fittings with electronic ballasts, triphosphor tubes and specular reflectors. The average throughout-life light level has been maintained, but the installed lighting load has been reduced from over 20 watts/m^2 to 11 watts/m^2, a saving of nearly 50%. The payback period for the extra investment over a conventional low capital cost upgrade was four years.

While occupancy and operating hours have doubled, energy costs have decreased by $3000 a year, with a further $4000 a year saving in maintenance costs.

9.6 St Lukes Shopping Centre

During 1990 and 1991, the 20-year old St Lukes Shopping Centre in Mt Albert, Auckland, was upgraded and expanded. The refurbishment won a Beta Award in 1994. The changes made to the shopping centre emphasise how energy savings can be made through greater use of daylighting, lighting control and computer-controlled airconditioning. While the lettable floor area was increased by over 70% (from 19,137 m^2 to 32,920 m^2), consumption of electricity barely rose and natural gas demand fell substantially. Electricity consumption per trading hour has fallen 4%. The simple payback period for the lighting and airconditioning upgrades was less than four months. The key energy management features of the refurbishment were:

- increased natural lighting and solar heat gains;
- efficient lighting, controls and extensive zoning;
- computer-controlled airconditioning and fresh air inflows; and
- careful airconditioning plant selection.

As part of the refurbishment, as many of the roof areas as practical were replaced with glass skylights. This, combined with planting of trees and other landscaping, has enhanced the amenity of the East Mall, West Mall and Centre Court areas of the centre. Penetration of daylight through these areas has significantly lowered the lighting power consumption and winter passive solar heating gains have reduced boiler energy consumption. The erection of sunshades in summer has successfully dealt with the potential problem of overheating (or, rather, extra airconditioning loads).

Figure 9.5: St Lukes Shopping Centre (photo courtesy of *Build* Magazine)

The number of major lighting zones has been dramatically increased. The carpark now has six separate zones that can be independently controlled. Sections of the carpark lights can be turned off when not needed, such as when a major store is trading but the mall itself is closed. The staff carpark lights are controlled by a timeclock so that in winter months staff can arrive and depart safely for a period before and after shopping hours. The carpark areas operate on half lighting, except for late night trading.

The mall originally had full and half lighting. There are now three zones with adjustable lighting levels. During daylight trading hours, only half lighting is used. The full level of lighting is only utilised when a light sensor in the East Mall skylight registers less than 100 lux. All lighting for service areas, loading bays, etc., is automatically turned off when personnel depart and set up a security zone (of which there are 11) by using a swipe card (lighting only comes on when somebody enters the zone). All carpark and security zone lighting is long-life, high efficiency 36 W triphosphorus fluorescent tubes. The balance of the lighting is either metal halide or low-wattage accent lights.

The original airconditioning system was operated by time clocks with electric-to-pneumatic controls. All clocks and controls have now been replaced with a Staefa Lantrol system, which was recently upgraded with a Staefa MS2000 building management programme. This programme manages over 50 airconditioning zones. The MS2000 software provides a graphical interface that helps with early fault detection and reporting functions for programmed maintenance. As well as reducing maintenance and service costs, this programme helps to keep the system running optimally — system deterioration over time is a major cause of loss of energy efficiency and utility with HVAC systems.

The air handling units controlled by the Staefa system have full outside and return air capabilities. When outside temperatures are very cold or hot, the inflow of fresh outside air is minimised. Under more favourable conditions, the system calculates the optimum mixture of return and outside air to take advantage of the potential heating and cooling contribution of the latter.

Additional chilling capacity was needed as a result of the shopping centre refurbishment and expansion. To provide an efficient yet flexible response to chilling loads, a Carrier air-cooled 353 tonne reciprocating chiller was chosen to complement the existing centrifugal chillers. The Carrier unit can obtain high efficiencies across a wide load range, even covering quite low loads. This allows the centrifugal units to be operated in their best efficiency range.

In addition to the above energy management improvements, steps have been taken to reduce peak load and improve the plant factor. All incoming power is regulated by a Metalect 6- and 8-step power correction unit, which controls the power factor between 0.95 and 0.98. The lighting circuits in the mall and carpark are controlled by a special switching system. The associated software allows individual circuits to be switched at three-minute intervals, which eliminates high startup demand. The reciprocating chiller has an Aucom Aucodrive electronic soft start, which reduces the direct on-line starting current from 497 amps to 138 amps per phase and reduces wear and tear on the motor and switchgear.

Refurbishment of the St Lukes shopping centre presented an opportunity to not only increase the floor space and enhance the shopping environment, but also to improve the energy efficiency of the complex. Many of the changes and upgrades were made to bring the centre to a very high standard to ensure its commercial viability well into the future. A number of the investments, however, can be identified as going that extra step towards greater energy efficiency. The payback period for these investments was just over three months. This highlights the point that paying attention to energy use is an important part of the commercial equation.

9.7 Quality Hotel, Palmerston North

During 1991/92, the Quality Hotel in Palmerston North installed a computerised energy management system to manage peak loads. Purchase of an energy management system was prompted by the offer of a tariff structure that charged separately for total energy consumption and peak demand, and hence provided an incentive to address these two cost components. Power cabling for many energy services such as refrigeration and water heating has been isolated and is now controlled remotely via timers connected to the computer. Loads are phased in or disconnected in order to keep peak demand below management targets as often as is practical.

The hotel also undertook two other initiatives that would not only reduce peak loads, but save energy as well. They were:

- key tag room switches were installed; and
- lighting for public areas was upgraded.

While the hotel's occupancy has increased by just over 20%, total electricity consumption has fallen by nearly 4%. The average energy demand per guest has dropped from 54.7 kW to 43.6 kW, a decrease of 20%. The Quality Hotel was a Beta Awards finalist in 1993.

The most recent addition to the hotel, the Tower Block, was built with key tag devices installed in the 73 guest rooms. The use of key tags to activate room energy services was subsequently extended to an additional two wings consisting of 36 rooms. The key tag, connected to the guest's room key, is placed into a slot in the entrance way of the guest room. This connects the power to the room's heating and lighting circuits. The power is then disconnected when the guest leaves the room and removes the key and tag. The system prevents wastage due to, for example, lights being left on when nobody is in the room — a common problem in the hospitality industry worldwide.

Based on the kWh/guest power consumption of the two wings with key tags versus those without, it appears that the investment of around $80 per room has a payback period of just over a year.

The standard 75 and 100 W incandescent bulbs in all the hotel's public areas were replaced with 9 W (40 W equivalent) and 11 W (60 W equivalent) compact fluorescent light bulbs. While the new bulbs are rated slightly lower than the bulbs they replace, lighting levels are perceived to be the same as before, if not better. The lighting upgrade has resulted in an 88% energy saving, which will pay back the investment in less than five months. Furthermore, there will be labour savings due to the longer life of the new bulbs (up to eight or nine months). The previous incandescent bulbs needed to be replaced about every 40 days.

The introduction of the above energy efficiency measures has made management and staff more aware of the benefits of careful energy use and their ability to achieve this, and the reaction of guests has also been quite positive. The comfort of guests has not been diminished in any way. As mentioned above, some people perceive an improvement in lighting levels. Guests have often noted the efficiency initiatives as a positive step by the hotel.

Figure 9.6: Key tag system, Quality Hotel, Palmerston North (photo courtesy of *Current* magazine)

9.8 KingsWay School, Orewa

KingsWay School demonstrates how a variety of design challenges can be addressed to provide a pleasant, cost-effective and energy-efficient teaching environment. This private Christian school, located in Orewa north of Auckland, had to be built progressively using largely voluntary labour and a fair degree of donated goods. It was completed in April 1991, and the school is showing an energy performance well above expectations. During the 1991 winter, the average total heater power usage was only 75 kWh/day, compared to the design specification of 168 kWh/day. KingsWay School was a Beta Awards finalist in 1993. The efficiency of the school buildings can be attributed to the following features:

- building orientation for solar gain and wind protection;
- use of small, easily-heated teaching spaces and vestibules;
- high levels of natural lighting and ventilation; and
- heater controls and circulation fans.

The buildings are oriented so as to be protected from the colder south/southwesterly winds and generally have a northeasterly aspect to maximise morning solar gain. All spaces are interconnected by an external covered walkway. Ideally, this would be located on the south side of the building. In this particular case, however, as the walkways and verandahs were considered an ancillary teaching space and were expected to contribute to outdoor seating requirements, they were established on the northern side. Nonetheless, the width of covered walkway roofing was reduced to ensure adequate natural light penetration to teaching spaces.

Hexagonal-shaped, relatively small classrooms were adopted to enable as many northeasterly aspects as possible. To balance the small teaching spaces, classrooms were grouped in modules of three, interconnected by three utility spaces — generally a teacher room, a resource room and a lobby/cloak room. Each classroom also had direct outside access for safety and occasional warm weather use. Figure 9.7 shows the plan layout of a typical module. This imaginative design provides internal access to resources and auxiliary space by all classes, reduced outside draft during cold seasons and the ability to provide good cross-ventilation during warmer seasons. Construction is concrete slab floor, insulated timber-framed classrooms and concrete block service areas.

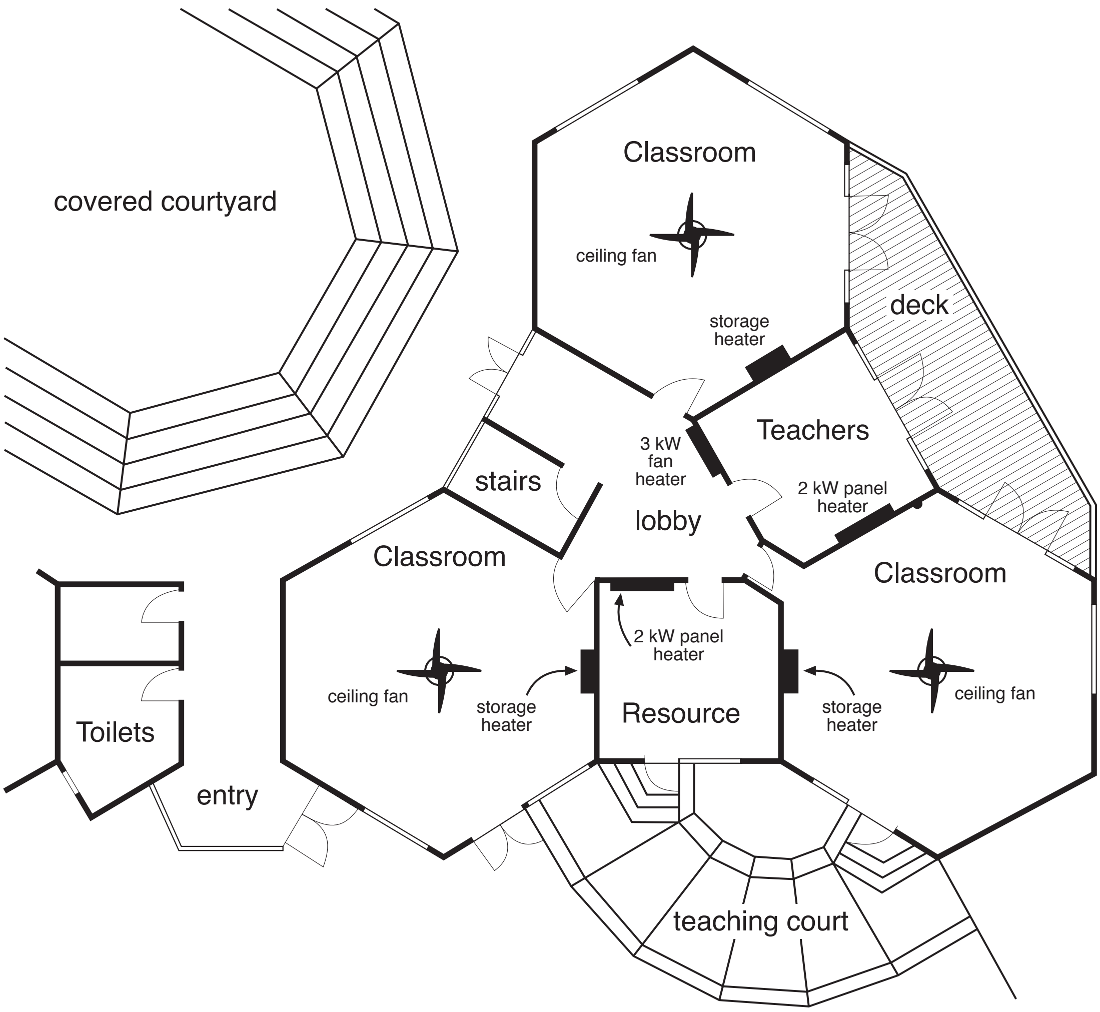


Figure 9.7: Typical module plan, KingsWay School

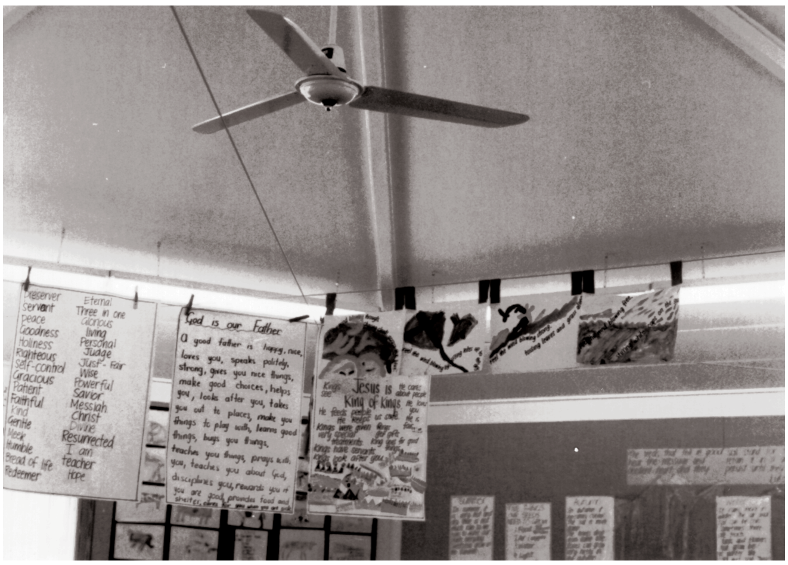


Figure 9.8: Ceiling fan, KingsWay School (photo courtesy of *Current* magazine)

Classroom heating is provided by Unidare MS27 fan-assisted storage heaters charged between the hours of 11 p.m. and 7 a.m. These heaters are supplied with two circuits — one for the heating element and the second for the fan control. The heater elements are on time clocks that allow for the heating to be turned off at weekends. The heater output fans are controlled via a time clock for pre-occupation classroom heating and a room thermostat for all-day comfort control. The thermostat is located on the opposite side of the classroom to the heaters. A low-speed fan at the ceiling apex of each classroom ensures even temperature distribution. This fan can also be used in summer to augment natural ventilation.

Because use of the lobby/teacher/resource area is intermittent, these spaces are heated with manually-switched, thermostatically-controlled heaters. The lobby has a Rolls fan heater, which can quickly heat this small space, while the teacher and resource rooms have panel heaters.

In summary, KingsWay School demonstrates that a pleasant, practical teaching and learning environment can be achieved at a low capital and operating cost for energy services.

9.9 Telecom Central Exchange, Christchurch

The new Telecom Christchurch Central Exchange demonstrates how effective management of heat gain problems can save energy and money. This new building received a Beta Award in 1994. An extra investment of $196,000 is expected to save over $200,000 per annum, giving a payback period of just under one year.

Telecommunication equipment produces heat, and cooling is needed to achieve the appropriate environment for such equipment. Several strategies have been used to address this issue:

- minimisation of solar gain;
- maximum use of cool, fresh air when available;
- energy efficient lighting; and
- good building zoning and control.

The lower floors of the building are not glazed and the upper floors are double-glazed with a reflective solar treatment to minimise solar gain. An integrated building management system (BMS) allows customised environmental control (within limits) for each of the 100 zones in the building. A localised variable-volume, variable-temperature airconditioning system was installed. Modelling indicated that this system would result in a 40% energy saving compared with a centrally-based airconditioning system.

The localised system meets the needs of the local zone directly, whereas a central system often involves reheating or cooling air to meet local requirements. Maximum use of fresh air is achieved through the use of a variable volume fresh air system. This system allows cooler outside air to enter the building when outside temperatures are appropriate and cooling is needed. Waste heat is recovered from chiller plant and reused in building zones that require heating. Around 80% to 90% of the building's heating demand is met from waste heat recovery.

Efficient lighting is used to save energy and reduce heat inputs. Lighting output is controlled by zone and three illumination stages to match changing occupancy levels and tasks. Infrequently used areas, such as the basement carpark, use motion sensor technology to control lighting. High frequency lighting control gear has been incorporated on some fittings. Speed controllers have been fitted to various motor loads, such as the water pumps and the basement exhaust fan, which run 24 hours a day. A 75% energy saving has been achieved on the exhaust fan, saving approximately $10,000 per annum for an investment of $3000. The savings on the water pumps is more modest, but still a significant 20%.

An interesting feature of Telecom Central Exchange is the installation of embedded generation. Telecom has two 500 kVA diesel generators primarily for standby backup should the main power supply to the exchange be interrupted. This generation can be run in parallel with the main supply through synchronisation equipment. This means a no-break change can be made from the mains to the generators, an important feature as power fluctuations can upset the sophisticated electronic equipment installed in the building. It also provides a number of important secondary benefits. On request from Southpower, Telecom can disconnect from the mains during power shortages or can generate its own power when power prices peak.

The capital cost of the synchronisation gear was $140,000. In its first year of operation, the system saved Telecom $70,000 in electricity costs. Another benefit of the system is that the BMS can regularly test the generation plant to ensure that all components are operating correctly and are prepared for an emergency.

Figure 9.9: Telecom Central Exchange, Christchurch (photo courtesy of *Current* magazine)

9.10 Weir House — Victoria University of Wellington

Weir House is a student hostel attached to Victoria University. It was opened in 1932 and a kitchen, dining room and common room extension was added in the 1960s. The original accommodation wing was recently renovated and the water and heating systems were upgraded at that time. This old wing has three floors with 75 students in single-room accommodation, plus a kitchenette and small flat on each floor.

Cold water supply was via gravity from roof space storage tanks. Hot water supply came from the same tanks via a calorifier in the basement. During times of heavy demand, gravity hot water supply to the upstairs outlets was pump boosted. The old water supply system had considerable pressure variation between the floors for both hot and cold water. Measured pressures varied from 150 kPa at the basement taps to 25 kPa on the second floor. As part of the upgrade, Platypus units were installed on all taps for handbasins, sinks and laundry tubs, and into the mixer valves used on the showers [3].

The Platypus system consists of a series of calibrated flow control units designed to limit and balance the flow of water from all outlets on a water reticulation system. The unit consists of an engineered brass insert, which can be retrofitted into any existing valve or tap body. It forms a new valve seat and controls the maximum amount of water through the valve. The supplier guarantees control of temperatures to within ± 1˚C and flow rates at all outlets to within ± 1 litre/minute. Table 9.2 shows the effect Platypus units had on the water outlets in Weir House. The system reduces both hot and cold water use while at the same time providing a better service, such as:

- stable temperatures at showers and other mixed water outlets;
- reduction in splashing at handbasins; and
- elimination of water hammer and associated noise.

By saving water, the water supply energy and waste water treatment energy demands are reduced. Monitoring at Wear House showed that total water use in the renovated wing was reduced by 20%.

From the building manager’s perspective, hot water energy use can be significantly lowered by installing Platypus valves. In the Weir House case, the volume of hot water use was reduced by around 50% (see Table

9.3) and the total hot water energy input was reduced by 24%. Energy and hot water volume savings do not coincide due to the fact that, before installation of the Platypus system, the hot water delivery temperature dropped at peak demand periods as the system struggled to cope with the load. Now the system can provide enough hot water at a stable temperature to meet peak demand while saving energy. This is because peak water demand has reduced by 56% without compromising an adequate flow and stable temperature supply.

Platypus Valves Installed			
Type of fitting	**Number installed**	**Initial Flowrate l/min (range)**	**PlatypusFlowrate l/min (average)**
COLD			
Shower mixing valve	20		4.7
Quarter turn tap	25	10 - 15	4.0
Bib tap	22	8 - 16	5.5
HOT			
Shower mixing valve	20		4.0
Quarter turn tap	25	12 - 15	4.6
Bib tap	21	10 - 15	5.6
Shower (mixed flow)		12 - 14	6.5

Table 9.2: Regulation of flow rates with Platypus valves

Platypus Valves Installed			
Type of fitting	**Number installed**	**Initial Flowrate l/min (range)**	**PlatypusFlowrate l/min (average)**
COLD			
Shower mixing valve	20	—	4.7
Quarter turn tap	25	10 - 15	4.0
Bib tap	22	8 - 16	5.5
HOT			
Shower mixing valve	20	—	4.0
Quarter turn tap	25	12 - 15	4.6
Bib tap	21	10 - 15	5.6
Shower (mixed flow)		12 - 14	6.5

Table 9.3: Hot water savings from Platypus valves

Economically, the upgrade has been a success as well. Water charges are down 20% and natural gas costs have fallen 24%. Based on these savings, the payback period is around 18 months.

End Notes

1 The Beta Awards Scheme has been established by the Electricity Supply Association of New Zealand to recognise the contribution electrical techniques and services can make to the energy efficiency of commercial buildings. Awards are presented in three categories: category 1 is for retrofits in buildings up to 600 square metres; category 2 is for retrofits over 600 square metres; and category 3 is for new buildings.

2 For information on the monitoring of the National Mutual building upgrade see EECA Project Summary 37, April 1994.

3 For information on the Platypus installation at Weir House, refer to EECA Project Summary 45, September 1994.

Contributing Personnel

Contributing personnel to the Commercial and Institutional Buildings Task Group were:

Mr Bill Brander, EECA, Wellington (Leader)

Mr Ian Shearer, ECNZ, Wellington

Mr Geoffrey Rands, GF Rands Consulting Engineer, Auckland

Ms Alison Barrett, Land Transport Safety Authority, Wellington

Mr Stuart Bridgman, SBE Consultants, Wellington

Mr Graeme Robertson, Department of Architecture, University of Auckland

Mr Hamish Handley, Building Industry Authority, Wellington

Mr Keith Gibson, Beca Carter Hollings and Ferner, Wellington

Mr Mike Donn, School of Architecture, Victoria University of Wellington

Mr Rob Bishop, Energy Solutions, Wellington

Mr Graham White, EECA, Auckland

Part 3

Transport

Contents of Part 3: Transport

Chapter 1
Transport Energy Use — Historical Perspective

1.1 Report Scope and Limitations

This section of Volume 1 is concerned with improving the energy efficiency of transport. It covers the movement of goods and people by vehicles of various sorts rather than via conveyors, lifts or pipelines. It does not explicitly cover the energy used to move people or goods within manufacturing sites or buildings, or during farming operations, although the vehicle technologies presented here will be relevant to some of these activities. The focus is on the movement of goods and people between farms and factories; factories, warehouses and shops; homes, work and other activity centres.

The information presented here relates to the operational energy requirements rather than embodied energy within the transport infrastructure and vehicles. This limitation should not be taken to imply that embodied energy is insignificant. The energy required to manufacture a motor car can amount to 25% to 30% of the fuel consumed by the vehicle during its lifetime. Furthermore, there is the matter of the energy used to construct roads and bridges, parking buildings and other transport-related facilities.

The omission of embodied energy considerations is the result of both resource and data constraints. Arguably, it is not a serious limitation. New Zealand already has a comprehensive transport infrastructure and more often than not the issue will be one of change on the margin rather than starting from scratch. However, in some cases, such as comparing the option of a major new length of motorway with a rail or light rail alternative, the issue of embodied energy may be relevant.

This first chapter provides an overview of transport in New Zealand, its historic development and current characteristics. Data on current and forecast transport energy use and its breakdown between modes are presented. An outline of the composition and characteristics of each major transport mode is provided, and the energy efficiency trend for each mode is presented and discussed.

1.2 Motivation for Energy Efficiency

Energy efficiency in the transport sector cannot be divorced from several other private, corporate and national objectives or motivations. Some of these support energy efficiency improvements, while others may, at times, act to oppose them.

Transport — a Derived Demand

Unlike other economic sectors, transport is a mostly a "derived" demand — people or goods being carried from one place to another is a reflection of activities taking place at the origin and destination of the journey. As a general rule, transport is a means to an end. In a few cases, vehicles are used in the performance of activities or to provide significant services other than moving from origin to destination (e.g. tourist sightseeing). Comfort, safety, short journey times and other amenities are, of course, expected by people when travelling and this can affect the type of vehicle chosen, how it is operated, etc. The key point, however, is that the motivation for transport is usually to shift goods to where they are needed or because people want to conduct an activity at a distant location.

Economic Benefit/Environmental Degradation

In general, improved transport services are regarded as a stimulus to economic activity, whereas constraints on transport are regarded as detrimental. For example, transport allows surplus goods to be moved to where they can be used. Society initially developed walking and bridle tracks, coach roads, river and coastal shipping and then railways to meet its needs for a transport system to facilitate economic growth. With the advent of motor vehicles early this century, transport within New Zealand became increasingly focused on cars and trucks.

New Zealand has subsequently experienced a similar interplay of forces as other nations with the same transport focus. As the cost of transport is reduced through improved road systems, cheaper vehicles and lower fuel prices, this in turn encourages new transport demand. Eventually, the negative externalities of transport systems — air pollution, noise, danger — become a general burden on society and the space to accommodate new traffic becomes limited, leading to congestion, loss of transport efficiency and environmental degradation. These effects are much more evident in other countries than they are in New Zealand, but problems do exist here, albeit to a lesser extent, and are becoming more evident over time.

Social Objectives and Energy Efficiency

Energy for transport is predominantly derived from fossil petroleum fuels, and this situation appears likely to continue well into the next century. Eventually, as the price of oil rises in response to either depletion of the reserves, or the imposition of pollution levies, renewable sources may offer an alternative source of liquid fuels.

Thus energy efficiency in transport is closely connected with objectives for conserving the use of petroleum fuels or reducing the externalities of their use. At various times these objectives have been to:

- maintain national security of fuel supply;
- limit foreign exchange expenditure;
- achieve long-term sustainability of resource use;
- limit local environmental pollution; and
- limit global effects such as greenhouse warming.

Security of Supply — the 1970s/1980s Response

Security objectives have been pursued at a public policy level and, while acknowledged by individual members of the public, the actions taken have usually stemmed from government initiatives. In the "energy crisis" period of the 1970s and early 1980s, energy security and foreign exchange issues were paramount. New Zealand was faced with rapidly escalating prices for petroleum products, which were almost entirely imported and for which the security of supply was in question. The response at that time was directed towards New Zealand becoming more self-sufficient in fuel supply. The actions taken were to reduce the demand for fuel through conservation measures (such as carless days and weekend petrol sales bans), while at the same time developing New Zealand's own oil and gas reserves (and the downstream technology to match them with the transport system — hence, the Mobil synfuels plant and the alternative fuels programme).

Sustainability and Environment — the 1990s Response

In the 1990s, the objectives driving the cause of energy efficiency in transport are different from those of a decade ago. Oil prices have fallen in relative terms and there are no immediate threats to supply. However, there are new concerns. Sustainable resource use has developed as a major public issue and this has implications for the transport sector. There is more concern about the externalities imposed by the transport system, such as accidents, noise and air pollution, and the costs of these on society must now be quantified and accounted.

Car-based transport systems require large tracts of land for roads and parking spaces. In some instances (e.g. the Wellington motorway extension), there is controversy over the potential loss of inner city residential neighbourhoods, historic buildings or open space to make room for motorways and parking buildings. The greenhouse effect has given rise to concern over the large contribution to national carbon dioxide emissions from the transport sector (just over 40% for domestic travel and over 45% if international bunker fuels are included (Ministry of Commerce, 1995)) which are related directly to the quantities of liquid fuels consumed. Some critics raise the issue of whether our present transport systems are sustainable in the long term.

Corporate and Private Motivations

Most New Zealanders consider fuel efficiency an important matter in the purchase of a car (MRL, 1993), however factors such as performance, comfort, quality and price generally come first (Collins, 1993). Once a car is purchased, day-to-day decisions on its use are often made on pragmatic or short-term needs. These considerations appear to apply equally, or more so, to company car use. When improved energy efficiency is consistent with these stronger motivations, then energy efficiency initiatives can be promoted in partnership and are more likely to be successful; where there is conflict, then energy efficiency will usually lose out. Some businesses are making a connection between energy efficiency, cost reductions, road safety and corporate image. A number of businesses have fleet management initiatives that include energy efficiency objectives. In some cases, these initiatives are supported by oil companies through the use of fuel purchasing cards and vehicle record schemes. Heavy truck operators are also concerned about fuel use from an economic perspective. The log trucking industry recently announced a good driver policy that included a commitment to adhere to speed limits. Part of the motivation for this policy was undoubtedly to improve public safety perceptions, but the practical effect will be to save fuel, tyre wear, etc.

In the long term, it may be possible to change the priorities and behaviour of the majority of people through a mixture of market signals, regulation and education. It will not be easy to reduce the need for transport, as such, in New Zealand due to the special features of the country (Section 1.3), but it should be possible to make the movement of goods and people more efficient through changes to vehicles and fuels and, to a degree, modes of transport.

1.3 Special Features of New Zealand Transport

New Zealand's geography and history has shaped the development of its settlements and transportation system and this, in turn, has contributed towards the pattern of energy use.

International Links

As an island nation, New Zealand has no external land borders and all overseas transport is dependent on sea and air. Relatively long international journeys are involved compared to most other countries, but, at the same time, New Zealand is highly dependent upon its external trade. Therefore, it has a vested interest in the cost efficiency of international shipping and air transport, even though much of this transport industry is outside of its ownership and direct control.

Effects of Geography

Internally, the two main islands dictate the need for inter-island transport by air or sea, and the elongated shape of the country makes for relatively long inter-urban routes in relation to the country's population density. Historically, European settlement and the introduction of mechanised transport began in the mid-1800s. Because of the rugged nature of the interior, the main settlements developed at coastal locations and coastal shipping was the principal form of communication in those early years. Later, the rail system was used as a tool for rural agricultural development, although the difficult terrain led to a decision to employ a very narrow gauge, which has been a constraining legacy on rail transport ever since.

Urban Transport and the Car

Expansion of the urban centres coincided with the invention of the automobile and, while public transport, particularly the street tram, was influential in the early part of the century, mass production of cars led to a low density pattern of urban settlement similar to cities in North America. The low urban density and dispersed settlement pattern is the rule in all but a few instances. One notable exception is Wellington, where the landform has concentrated traffic flow into natural corridors and the public transport system plays a greater role.

Car ownership grew rapidly after World War II, despite import controls that remained in place until the 1970s, and there is no sign that demand is saturated (Collins, 1993). This growth has weakened the position of public transport, which has seen a gradual but continuous erosion of its market over time. Except in a few localities with favourable circumstances, it does not appear to be economic to reverse this trend. It may be that the externalities of car transport (e.g. pollution) are underpriced. If so, correcting this problem would expand the opportunities for cost-effective public transport. Nonetheless, for the foreseeable future the dominant mode for personal mobility in New Zealand is likely to remain the motor car.

International Comparisons

Internal transport consumes about 34% of consumer energy in New Zealand, a proportion higher than in most European countries and on a par with Australia and the USA. If international transport that is refueled in New Zealand is also included, then transport in total makes up over 40% of the consumer energy demand in New Zealand.

The proportion of transport energy does not, however, correlate well with a country's population density or level of development. Densely-populated Hong Kong has a high transport share (39%) as do some developing countries, such as Ecuador. The relative proportion of energy going into transport can be as much a measure of the level of energy use or efficiency in other sectors, such as industry, as the efficiency of transport systems.

Personal mobility in New Zealand is estimated to be around 11,000 km per person per year of travel (Beca Carter, 1994). With the exception of the USA, where the total travel per capita is about 22,000 km, most developed countries have similar levels to New Zealand. Car travel accounts for 80% to 85% of passenger-km in most developed countries, including New Zealand.

Car ownership in New Zealand is one of the highest in the world and is still growing (IEA, 1991). Among the OECD nations New Zealand car ownership, at just over 500 cars per 1000 people, is second to the United States (just over 570 cars per 1000 people). The specific energy demand of car travel in New Zealand is thought to be just over 2 MJ per passenger-km. This is higher than for most European countries (except West Germany), but lower than for the USA (2.7 MJ/p-km).

1.4 Transport Energy Use and Trends

Internal transport in New Zealand consumed around 140 PJ of energy in 1993, mostly in the form of liquid fuels. International transport accounts for another 32 PJ.

Road transport is the predominant user of energy within New Zealand, accounting for 90% of total transport energy demand. The next largest user is domestic air transport (7%), with rail and coastal shipping accounting for the remaining 3% of use. Around half the transport energy used is in motor cars. A small amount is used for buses and taxis and the balance for goods transport (see Section 1.5).

On a per capita basis, New Zealanders use an estimated 42 GJ/head/year of energy for transport within New Zealand. On average, each New Zealander uses more than half this total, perhaps 25 GJ, for personal mobility — travelling to work, flying between cities, etc. To put this in perspective, the average New Zealand home uses around 40 GJ per annum for heating, lighting, etc. If this hypothetical home has two adults and two children, then the energy used for personal mobility for the family could be as much as 100 GJ, far more than needed to heat, light and power the home.

Figure 1.1 illustrates the historic changes in transport energy use since 1974 (Beca Carter, 1994). After a period of relative stability from the mid-1970s to the mid-1980s, transport energy consumption in total and on a per capita basis rose steadily. On a per capita basis, the current growth rate is over 2.5% per annum, which, coupled with a population growth rate of around 0.8%, gives a total rate of increase of over 3%.

In the future, the rate of growth is expected to ease but still be significant. The average rate of growth in the transport sector over the 30 years 1990 to 2020 is expected to be 1.8% each year (Commerce, 1994). Table 1.1 shows the baseline outlook for transport and the other major energy-using sectors (Commerce, 1994). This baseline scenario represents a business-as-usual outlook with no major technological breakthroughs, international trade conflicts or shifts in government policies. The transport entries include international transport. Transport energy use may rise by 110 PJ or more over the next 30 years (an increase of around 70%). Its share of total consumer energy could increase from 43% to nearly 50% over this time period.

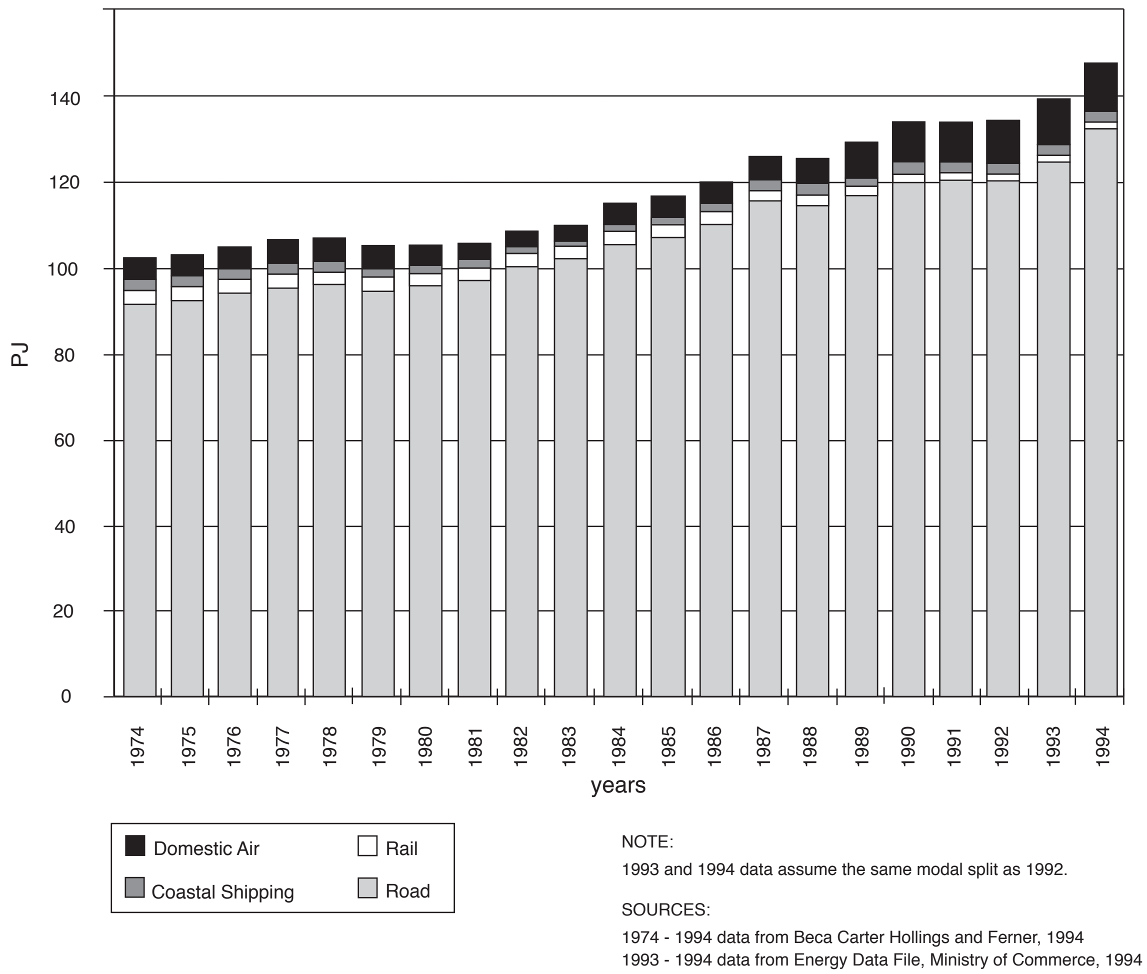


Figure 1.1: New Zealand energy use in transport (Beca Carter, 1994)

March years	Residential	Industrial and Commercial	Transport	Total
1990	41.2	171.8	164.4	377.5
1995	44.9	182.3	178.3	405.5
2000	46.8	203.1	190.0	439.9
2005	48.8	221.1	206.9	476.9
2010	49.6	208.6	228.5	486.7
2015	50.0	219.9	253.4	523.2
2020	50.4	232.7	281.8	564.9

Table 1.1: Total consumer energy by sector (PJ) (Commerce, 1994)

Clearly, it is important to examine any technologies and transport management systems, and any potential for changing the demand for transport that might reduce the future transport energy consumption (or otherwise mitigate the adverse effects of moving people and goods). In doing so, it is important to realise that the potential of different transport technologies and public policies to improve transport energy efficiency will vary from country to country according to the existing transport infrastructure, population patterns and economic activities.

1.5 Road Transport

Energy Consumed by Road Vehicles

While road vehicles may not always be the most energy efficient means of transport (see Section 1.7) economic considerations, reinforced by New Zealand's pattern of settlement and geography, indicate that a significant change in transport mode is unlikely in the foreseeable future. The dominance of road transport, and the likelihood that this will continue, emphasises the need to address this sector in any initiatives to improve transport energy efficiency.

Within the road transport sector, energy consumption is dominated by the private car. Table 1.2 shows how energy consumption is divided between the different sub-sectors of road transport (Bone, 1994). Private and company car use make up over 50% of the total road transport energy consumption. The next largest sectors are heavy and light goods transport, respectively.

Road Transport Sub-sector	PJ	%
Cars	69.1	52.8
Taxis and Rental Vehicles	1.6	1.2
Public Buses	7.7	5.9
Light Goods Vehicles	24.2	18.5
Heavy Goods Vehicles	25.6	19.5
Motorcycles	0.5	0.4
Miscellaneous	2.3	1.8
TOTAL	131.0	100.0

Table 1.2: Energy Consumption in road transport, 1992 (Bone, 1994)

Between them, cars and goods vehicles account for over 90% of the energy used in road transport. It is, therefore, important to concentrate on efficiency gains in these forms of road transport.

Road transport is dominated by vehicles powered by internal combustion engines. In 1971, a noted transport commentator (Gunston) said that:

> *it could be argued that since 1885, there has been no really fundamental change in the design of road vehicles ... the traditional Otto-cycle four stroke petrol engine has proved amazingly enduring...*

Gunston went on to speculate that "by the 1980s the picture could be quite different", and looked to the development of rotary engines and gas turbines for road vehicles. However, by the mid-1990s the situation has not changed and road transport is still dominated by evolutionary development of reciprocating four-stroke spark ignition and compression ignition engines.

At the risk of further false predictions, it can be argued that the development of road vehicles is now at the turning point. Environmental concern over vehicle emissions is proving to be a powerful motivating factor for change. Engine improvements, new engine systems, alternative fuels and lighter and more aerodynamic bodies are foreseeable, along with better roading infrastructure and traffic control. Of course, road vehicles have relatively long lives, so it would take many years before some of these changes had a significant impact on overall fleet performance.

Characteristics of the Vehicle Fleet

Private Cars and Motorcycles

The New Zealand vehicle fleet is old in comparison with other western industrialised nations. The average age of private cars is 10.6 years. Heavy diesel goods vehicles average 9.9 years of age and diesel buses 12.6 years. The mean age of buses has, in fact, decreased over the past decade. The mean age of cars (historically in the range of 8.5 to 10.5 years old) is increasing, notwithstanding the influx of used Japanese vehicles, which now account for about 16% of cars on the road. These imports have displaced some older vehicles but have also cut into new car sales. On average, overseas imports are five to six years old at the time they enter New Zealand.

The annual kilometres driven by cars and other vehicles tends to decrease with age. The average car will run 20,000 km in its first year, but this drops to around 10,000 km by the time the vehicle is 12 years old. People prefer larger cars for long-distance travel and this is reflected in the statistics that new cars over 2.0 litres travel around 22,000 to 23,000 km/year, while cars under 1.3 litres travel only around 17,500 km in the first year.

The average engine capacity of cars in use is now just below 1.9 litres. The average engine size of new cars has risen from a low point of 1.7 litres in 1980 to 2.0 litres in 1992. In 1994, the average engine size of new cars was again over 2.0 litres. The recent rise in average engine size has been at the expense of the small car (under 1.35 litres), which has held an ever-decreasing market share since 1980, at which time this group accounted for 40% of sales, compared with 10% in 1992. In addition, since 1986, the share of the new car market taken by cars over 2.0 litres has increased from 7% to around 30% in 1992.

If the Economic Commission of Europe (ECE) fuel consumption test results are plotted for a range of vehicle sizes, then considerable scatter is found. The line of best fit represents a linear relationship with each litre in engine capacity equating to a fuel consumption of 1.4 litres/100 km under highway conditions, or 3.7 litres/100 km under urban conditions. The degree of scatter for vehicles in the popular mid-range of 1.35 to 2 litres is such that some larger engine cars are more efficient than the poorer performing of the smaller cars.

The proportion of the car fleet that uses fuels other than petrol are 1.3% diesel, 1.7% CNG and 0.9% LPG. Diesel-powered cars formed a very small part of the fleet until the large increase in used car imports, which account for 80% of the diesel cars now in use.

Motorcycles form only 8.4% of all vehicles and the total number is in sharp decline, falling from around 150,000 a decade ago, to only about 74,300 now. New registrations have dropped from a peak of 30,000 in 1980 to 2500 in 1992. The net effect of this drop on overall fuel economy is hard to assess as one ex-overseas car may substitute for more than one motorcycle, but cars are likely to travel further and, overall, the effect on energy use is probably an increase.

Company Cars

Private cars are cars other than rental and hire cars and taxis. A number of private cars are company cars, that is owned by businesses or operated to a large extent for commercial purposes. It is difficult to estimate the number of company cars. From the vehicle registration record, around 9% of cars are listed as being owned by a company. However, this ignores those registered to self-employed individuals who share the use of the vehicle between business and home.

Since the imposition of fringe benefit tax on company cars a few years ago, there is no doubt that the number of business vehicles has declined to a minimum. It used to be said that around 50% of new cars were purchased by businesses and, with very few used car imports, the choices made by the business community had a considerable influence on the choice of cars available to the average second-hand car buyer. With the advent of ex-overseas imports, the situation has changed somewhat and, as the duty and tax on new vehicles has also decreased, the private buyer now has more influence on both the new and used car market.

Company vehicles are thought to be on average larger, at 2.0 litres, than household cars and have higher annual utilisation, at 20,000 km/year compared with 13,300 km/yr for the car fleet as a whole, but these figures are only rough estimates. It would be useful to have reliable data on the relative numbers and characteristics of the business car fleet as different methods may need to be employed to encourage energy efficiency in this group compared with truly privately-owned vehicles. The users of some company cars, for example, do not pay for the petrol used and thus do not face one of the incentives for economical driving.

Buses and Heavy Vehicles:

There are some 6000 large buses in use, of which two-thirds are diesel-powered, about 2% CNG-powered and about 2% LPG-powered. The balance are petrol-fuelled, with the exception of Wellington's 70 trolleybuses. Auckland discontinued its trolleybus system around 1980.

The bus fleet has been growing over recent years, which is mainly the result of increases in tourism rather than in urban public transport. The patronage of urban transport services, with a few exceptions, is slowly declining.

Heavy freight vehicles are almost entirely powered by diesel engines, whereas light goods vehicles, such as courier vans, appear to have a mix of petrol, diesel, CNG and LPG-powered engines. The average annual kilometres for light goods vehicles with diesel engines is around 17,000 km/yr (from Road User Charges data). The average utilisation for heavy vehicles has risen by around 40% since 1986/87 to over 50,000 km/yr. A small percentage of heavy vehicles is likely to be clocking up high mileages, perhaps 100,000 km per annum, thus contributing disproportionately to the overall average. These long-haul vehicles should be the main focus of energy efficiency initiatives for heavy vehicles.

Energy Efficiency Trends

Limited data makes it very difficult to estimate the trends in energy efficiency of transport, but a recent attempt has been made (EECA, 1995). Table 1.3 summarises the best available data for the main transport modes. Two modes — bus transport and domestic air — show a deterioration in energy efficiency over the period 1985 to 1992. Table 1.4 shows a detailed breakdown of car energy efficiency parameters for the years 1975, 1986 and 1992 (Beca Carter, 1994). If the estimates are correct, then the energy efficiency of private cars (litres/100 km) has improved by 13% from 1975 to 1986 and by a further 8% from 1986 to 1992. The improvement is largely attributable to improved vehicle technology. The gains have been partly offset by reducing vehicle occupancy and the increased use of energy-consuming accessories. Table 1.5 shows that occupancy is thought to be slowly decreasing, a trend consistent with a gradual rise over time in the numbers of cars per capita. The effect of decreasing occupancy is shown in the bottom row of Table 1.4. The percentage improvement in efficiency, measured in terms of KJ/p-km, is not as great as the improvement in fuel economy (*l*/100 v-km). Between 1986 and 1992, passenger fuel efficiency improved by only 5%, whereas vehicle efficiency improved by 8%.

Load factor, or the average number of passengers in a bus (or train), is an important determinant of public passenger transport efficiency. Load factor is a function of the total number of passengers, bus size and frequency of services. Unfortunately, there is no uniform database available to analyse national trends in load factor. Data for Wellington and Auckland show a substantial decline in bus patronage over the eight years to 1992. In Auckland, for example, travel into the city centre during the morning peak dropped from 25,000 passengers per day in 1986/87 to under 15,000 passengers per day in 1992/93, a reduction of 40%. In Wellington, the decline appears to have been less pronounced, and the total number of passenger boardings (an indicator of use) has fallen 24% over a similar period. Patronage in Wellington and Auckland appears to have stabilised, or even increased slightly, since 1992.

	Private cars (MJ/p-km)	Bus transport (MJ/p-km)	Commercial road (MJ/tonne-km)	Freight rail (MJ/Net tonne-km)	Passenger rail (MJ/p-km)	Domestic air (MJ/p-km)
1985	2.10	0.73	3.51	0.85	1.24	3.26
1986	2.15	0.74	3.47	0.86	1.24	3.40
1987	2.19	0.74	3.45	0.88	1.24	3.37
1988	2.05	0.75	3.45	0.86	1.24	2.94
1989	2.05	0.77	3.44	0.83	1.24	4.29
1990	2.05	0.78	3.38	0.89	1.24	4.29
1991	2.03	0.79	3.34	0.78	1.24	NA
1992	2.00	0.80	3.27	0.77	1.24	NA
Change in 1992 over 1985	-4.76%	9.16%	-6.99%	-9.06%	—	NA
Change in 1992 over 1991	-1.48%	1.33%	-2.17%	-1.12%	—	NA

Table 1.3: Transport energy efficiency indicators, March year ended 1985 - 1992 (Based on information compiled from Beca Carter Hollings and Ferner, reported in EECA, 1995)

In the future, the rate of growth is expected to ease but still be significant. The average rate of growth in the transport sector over the 30 years 1990 to 2020 is expected to be 1.8% each year (Commerce, 1994). Table 1.1 shows the baseline outlook for transport and the other major energy-using sectors (Commerce, 1994). This baseline scenario represents a business-as-usual outlook with no major technological breakthroughs, international trade conflicts or shifts in government policies. The transport entries include international transport. Transport energy use may rise by 110 PJ or more over the next 30 years (an increase of around 70%). Its share of total consumer energy could increase from 43% to nearly 50% over this time period.

	1975	1986	1992
Litres/100 v-km	12.08	10.48	9.65
Mean Occupancy	1.78	1.71	1.64
Litres/100 p-km	6.78	6.12	5.88
MJ/litre	34.42	34.44	34.32
kJ/p-km	2330	2110	2020

Table 1.4: Changing energy efficiency of private cars (Beca Carter, 1994)

Year	Car Users/Car Drivers
1971	1.22
1976	1.20
1981	1.23
1986	1.14
1991	1.12

Table 1.5: Vehicle occupancy inferred from census data (Beca Carter, 1994)

From the limited data available, it is thought that the energy intensity of bus travel has increased from 730 kJ/p-km in 1985 to 800 kJ/p-km in 1992, a loss in efficiency of 10%. This result is probably the interplay of the negative factors of falling load factor and increased traffic congestion and the positive influences of economies from larger vehicles, better automotive engineering and substitution of diesel for petrol. Other than the reasonable likelihood that load factor is falling, the real picture with passenger bus trends is, however, uncertain.

Data limitations also make it difficult to estimate trends in the energy efficiency of goods vehicles. It is thought that the efficiency of light goods vehicles has improved, perhaps by as much as 30% in some cases over the last ten years, primarily as a result of a strong move from petrol to diesel. For heavy vehicles, the improvement over the last ten years may have been 20% (Beca Carter, 1994). Several factors would have contributed to this, including the introduction of lighter alloy body construction, an improvement in mean load factor and aerodynamic fairing. These improvements may not have been as widespread as initially thought, however. Table 1.3 indicates that overall commercial road freight only improved its efficiency (MJ/tonne-km) by just under 7% between 1985 and 1992. Average figures can mask significant improvements in some sectors. For example, long-distance line-haul operations, the most efficient form of road freight, are now considered to be on a par with rail and coastal shipping (Beca Carter, 1994), with an energy intensity of about 750 kJ/tonne-km (see Section 1.7).

1.6 Rail, Sea and Air Transport

A brief overview of trends in rail, sea and air transport is provided below. Refer to Chapter 7 for a more detailed discussion.

Rail Transport

Rail transport in New Zealand has undergone considerable change over the past 15 years. Historically, the railways system was operated as a government department and protected against competition from road freight transport. This protection was first relaxed and then removed, setting up the conditions that would allow the growth of long-distance freight transport by road, which had previously been confined to only a few specific freight commodities and locations.

This was followed by a programme of corporatisation, then privatisation of New Zealand Rail, drastically reducing the staff numbers, and shedding some of the less profitable business, particularly inter-urban passenger services. However, the reduction in freight tonnage was relatively minor and the company is now trading profitably, a considerable achievement over its days as a heavily state-subsidised government department.

There have been gradual improvements in the energy efficiency of rail transport over the years, from 1.00 MJ/tonne-km in 1970 to 0.77 MJ/tonne-km in 1992 (i.e. a little over 1% per annum). These gains are attributable to a variety of technical and organisational improvements. Milestones have included the replacement of the Wellington suburban railcars in the early 1980s, the electrification of part of the Main Trunk Line and, currently, the introduction of diesel-electric multiple units to the Auckland suburban service.

Sea Transport

Coastal shipping services are provided by a relatively small number of vessels and much of this transport is of liquid and dry bulks. Coastal general and roll-on/roll-off cargo services suffered a decline in the 1970s and through the first half of the 1980s, which was brought about by competition from other modes and through outdated industrial rigidities in the ports and shipping industry. The second half of the 1980s and the early 1990s have seen many of these constraints removed and coastal shipping, which appeared to be on the brink of collapse, has made a recovery to its former levels of the early 1970s. However, there appears to have been little change in the energy efficiency of coastal shipping, despite a gradual increase in vessel size.

Air Transport

Domestic air transport is dominated by two main carriers, Air New Zealand and Ansett New Zealand, and their associated link service companies. In 1990, domestic air transport had an average energy intensity of 4.3 MJ/passenger-km, a significant increase over 1987 levels, the year Ansett was allowed to compete against the national carrier. This change saw a considerable improvement in customer services but was accompanied by a reduction in overall load factors, which was sufficient to more than counteract energy efficiency improvements from the introduction of new aircraft. Air transport provides an example of where government's other public policy objectives run counter to improving energy efficiency.

1.7 The Energy Efficiency of Transport Modes

Energy Use per Unit Travel Distance

Table 1.6 below shows the comparative energy intensity of transport modes in New Zealand on a per kilometre basis (Bone, 1994). A comparison has been made between the energy intensity under the estimated average load factor (kJ/pass-km) and the energy intensity when the form of transport is operating at full capacity (kJ/seat-km). The figures do not allow for differences in route length, or the need to switch modes, factors that should be taken into account when comparing the energy efficiency of particular transport modes (Bone, 1994). The issue of mode comparisons is developed further in Chapters 6 and 7. Two of these issues, trip circuity and modal transfers, are introduced below. The embodied energy issue, although not developed further in this part of the project report, is also noted below.

Effects of Trip Circuity and Inter-modal Transfers

Road transport has the advantage of directness, and private transport is generally more direct than public transport. In comparing the energy efficiency of one transport mode with another, these effects of trip circuity should be taken into account. For cars compared with buses in an urban area, the additional route length will normally be small for travel between the central area and suburban residential districts. However, for cross-town trips, which public transport has difficulty in serving, to undertake the trip by bus may involve one trip into the centre and another out again, possibly adding up to 50% additional route distance.

Similar considerations apply to comparisons between freight transport modes. With the exception of industries that have their own rail sidings, land transport by rail will involve a short access trip by road at each end of the rail journey together with the process of transferring the goods between road truck and rail wagon. A comparison of energy efficiency should, logically, include these access journeys and transfers.

Transport Mode/Vehicle	kJ/seat-km	Mean Occupancy	kJ/pass-km
Passenger Transport — Urban			
Private Car, 1800cc, 4 seats	850	37.5	2270
Motorcycle, 250cc, 1 seat	1400	100	1400
Urban Stage Bus, 53 seat	320	25	1280
Wellington Multiple Unit	NA	NA	450
Auckland Rail Unit	NA	NA	2000
Passenger Transport — Inter Urban			
Domestic Air, B737, 117 seats	2200	50	4400
Private Car, 1800cc, 4 seats	850	42.5	2000
Inter-Urban Bus, 40 seats	370	35	1000
Inter-Urban Rail	NA	NA	1400

Table 1.6a: Comparative Energy Efficiencies of Passenger Transport Modes (Bone, 1994)

Transport Mode/Vehicle	kJ/seat-km	Mean Occupancy	kJ/pass-km
Freight Transport — Long Distance			
Transport Mode/Vehicle	kJ/capacity tonne-km	Mean Load Factor %	kJ/freight tonne-km
Air Freighter	13 500	90	15 000
Rail Goods	NA	NA	860
Road Freight, 24 t payload	550	75	735
Coastal RoRo Vessel	NA	NA	1000

Table 1.6b: Comparative Energy Efficiencies of Freight Transport Modes (Bone, 1994)

Energy Input to Transport Vehicles and Track

As mentioned in Section 1.1, a life-cycle energy accounting approach is needed to fully appreciate the energy used in transport systems. Energy input to the construction of vehicles and to the provision and maintenance of track and terminals (roadway, rail line, ports, airports, etc.) makes a significant contribution to the total system energy cost.

While long-lived, most investment into fixed transport infrastructure, both financial and in energy inputs, is nonrecoverable. However, the situation is better for transport vehicles — steel and aluminium bodies can be recycled, although plastics and composite materials are harder to recover unless recycling has been built into the design philosophy. For example, in New Zealand, car bodies are recycled by Pacific Steel.

1.8 The Influences of Public Policy

Central government agencies and local authorities can exercise considerable influence on the energy efficiency of the transport system if they choose to do so. The ways in which public policy can bring influence to bear include:

- taxation and/or user charges on transport inputs — notably on new vehicles, vehicle use and fuel;
- controls on the ownership and use of vehicles, the availability of parking, etc.;
- public sector planning of urban development and transport infrastructure;
- sponsorship of education and training programmes, and publicity;
- financial support and/or concessions for technical research, development and demonstration programmes; and
- subsidising public transport capital or operating costs.

In New Zealand, the government has, in the past, become involved in most of the above. Examples include:

- the setting up of the New Zealand Energy Research and Development Committee (NZERDC) in 1974 (disestablished in 1988), which was funded by government grant to conduct research and development into all aspects of energy conservation;
- the setting up of the Liquid Fuels Trust Board (LFTB) in 1977 (disestablished in 1987), which was funded by a levy on petrol to pursue New Zealand's policy of greater transport fuel self-sufficiency;
- a CNG Co-ordination Committee to promote the development of the compressed natural gas industry;
- taxation that differentiated between cars by engine capacity rating;
- a short-lived voluntary vehicle fuel economy testing and labelling scheme for new cars;
- short-term rationing measures — such as "carless days"; and
- TV and press advertising, information leaflets for alternative fuels, fuel economy tips for drivers and public information centres.

The major thrust of public transport policy over the last 10 years has related to market efficiency rather than energy efficiency. Promotion of unleaded petrol is the only example of another objective being pushed. As a result, the government does not seem to have a transport energy efficiency policy. The NZERDC and LFTB have been disbanded, support for the CNG industry is not apparent, engine size-based taxation was removed prior to the introduction of the goods and services tax, the funding arrangements for public transport have been changed and market mechanisms to encourage energy efficiency in transport do not seem to exist. It seems as if energy efficiency is in conflict with other government objectives, is not considered as important or has simply been overlooked in decision making.

Recently, however, the government commissioned a land transport study. Part of this study is looking at the externalities of transport and whether they are reflected in the present price structure. The outputs from this study may have some effect on transport energy efficiency.

The government's climate change policy is focused on voluntary agreements with industry to reduce carbon dioxide emissions. This policy may extend to vehicle fleet operators and, hence, could have some minor effect on transport energy use, but overlooks the fact that most road transport energy is used in private cars.

The Energy Efficiency and Conservation Authority (EECA) has a responsibility to promote energy efficiency. While some educational material aimed at car drivers is produced occasionally, EECA's focus at present seems to be more on industrial and household energy use. The establishment of EECA should, however, ensure that in future energy efficiency implications are considered by government when public policy decisions are made.

Some local and regional authorities are developing transport energy policies. The Canterbury Regional Council, for example, is promoting exhaust emission testing of vehicles. While the motivation for this initiative is largely to reduce local air pollution, it may have an efficiency spin-off.

It is undoubtedly difficult to design public policies for transport energy efficiency that are consistent with other government policies and achieve improved efficiency in a cost-effective manner with no unwanted side-effects.

Chapter 8 of this report provides information and discussion on the type of policies that have been adopted or considered for use overseas.

Chapter 2
Sources of Improved Energy Efficiency

2.1 Introduction

Sources of Improved Energy Efficiency

Ways in which energy efficiency in the transport system can be improved include:

- vehicle technology advances — the technology improvement is driven by competition within the industry, by consumer demands and perceptions and, in some cases, by government regulation.
- improved load factors — the higher the load factor, generally the better the energy efficiency; the improved load factor can be achieved in various ways, such as a closer match of vehicle size to the demand and concentration of the demand by scheduling or spatial organisation.
- substitution of one vehicle type with another — these can take the form of alternative fuel/propulsion systems and substitutions of transport mode (cycle, motorcycle, car, bus, train etc).
- modification of the demand for transport — demand can be generated or suppressed by changes in the cost of travel, where "cost" is interpreted in a general sense meaning length of time, financial cost, comfort and convenience.

"Demand management", the fourth point above, is becoming a necessary feature of congested urban areas, although the scale and intensity of problems in New Zealand is still very low in comparison to overseas. Travel suppression implies that some consumer demand is not being satisfied, but the personal cost of this will vary in degree, depending on whether the activities foregone are being effectively substituted by others at another location, at another time of day.

The above fuel efficiency measures are listed in general order of increasing impact and degree of change from what is often referred to as the "business as usual" scenario. The greater the change required, whether in technology, the built environment or in human behaviour patterns, the harder this is to achieve and the longer it takes. The greater the change, generally the greater the influence of other personal and social objectives, and often these will not be supportive of improved energy efficiency.

The weight given to the energy efficiency objective will be largely governed by the cost and availability of fuel in the short- to medium-term in comparison with the other inputs to transport. At present, it appears that petroleum fuel supplies will be plentiful and relatively cheap well into the next century, so the pressures for fuel economy from the marketplace are limited. For some transport modes, energy forms a larger proportion of the inputs than for others. For example, as a proportion of operating cost, energy use in air transport is high, whereas for road transport it is lower, followed by rail and sea.

The following sections identify potential avenues for energy efficiency in transport. Each of these is developed further in the subsequent chapters of this report.

2.2 Vehicle Technology

Vehicle technology is the area from which most improvements in the energy efficiency of transport tasks have stemmed, with particularly large gains being made in the decade from 1974 to 1984.

New Zealand has a declining vehicle assembly industry, but not a significant vehicle manufacturing industry and its vehicle import volumes are small in comparison with most other countries. New Zealand industry is involved in some limited manufacturing of vehicle parts and accessories and has a well-developed coach and bodybuilding industry. Overall, the local industry has had little influence on automotive technology development, which is driven by requirements set in other, larger economies.

However, it is possible to have some effect on energy efficiency by being aware of developments in automotive technology overseas and being selective of what is imported. Bearing in mind that the average vehicle entering the New Zealand fleet can be expected to have a 20 year or greater lifespan, the legacy of inappropriate vehicle imports stays with the country for an extended period of time.

New Zealand has a reputation for inventing or adapting to meet market needs and, in the past, after-sales retrofit conversion has been used as a means of getting around the inertia of new technology supply from abroad, a successful example being the CNG and LPG fuels programme. However, the retrofit industry needs careful control and the full backing of the original manufacturers if warranties and after-market servicing are to be fully maintained. For such a small market it is not always feasible for manufacturers to give such endorsement. Furthermore, not all retrofit technology is of a high standard and many fuel-saving devices tested by the Automobile Association and the DSIR (now Industrial Research Ltd.) have been found to be ineffective.

For a particular retrofit product to become commercially accepted generally requires development and testing beyond the financial capacity of most New Zealand businesses. In such circumstances, the best that can be achieved is to develop the technology to a stage where it is proven and then on-sell to a larger overseas group. If successful, the product may return and be used on the New Zealand market and this has happened on a few occasions.

Chapter 3 "Vehicle Technology" provides an overview of technology developments taking place world wide that could substantially reduce the fuel consumption of cars and vans, trucks and buses.

Developments in automotive technology can be subdivided into the following areas:

- the engine and fuel system;
- the transmission system;
- accessory loads;
- tyre/road interaction;
- aerodynamic design; and
- lightweight body materials.

There are definite opportunities for New Zealand to influence energy efficiency, mainly in the last three areas, by:

- reducing the rolling resistance through attention to road surfaces and tyre selection;
- through aerodynamic design of coach and truck bodies, particularly for highway travel; and
- the use of modern, lightweight materials in the construction of coach and truck bodies.

2.3 Influencing Private Vehicle Ownership

Cars and light goods vehicles, whether purchased by the individual or by businesses, account for the majority of fuel use, so the initial purchasing decision is of some importance to fleet-weighted energy efficiency over the following years.

The three factors that most affect overall fuel consumption are:

- vehicle mass, as inertial, grade and rolling resistance are all mass-dependent and absorb considerably more energy than aerodynamic drag, transmission losses and other losses;

- fuel consumed when the engine is idling, which is approximately proportional to engine size; and
- thermal efficiency of the vehicle engine under load.

In view of this, regulations and taxation aimed at affecting the vehicle purchase decision are normally aimed at vehicle size, with engine cubic capacity used most often because of simplicity in administration. However, this is a somewhat imperfect proxy for fuel efficiency and some countries have attempted to more precisely target fuel economy by introducing standard test procedures and then using these as the basis of regulatory, taxation or publicity programmes. Examples are found in the United States, for example the Corporate Average Fuel Economy (CAFE) scheme based on the US Federal Test Procedure (FTP), and in the European Community, for example the Economic Commission of Europe ECE-15 Regulations. The Japanese also have their own 10 model test cycle, while the Australians have adopted a version of the FTP. In each case, the test cycles were introduced initially for the purposes of testing for and regulating atmospheric pollutant emissions.

New Zealand promoted a voluntary fuel economy labelling scheme in the early 1980s with the domestic vehicle industry and developed New Zealand standards for the tests and the labelling. These were essentially based on the ECE15 test cycle because many vehicles marketed in New Zealand were also sold on the European market and had undergone the necessary test. This was despite the fact that the ECE15 driving cycle is not representative of New Zealand conditions whereas the Federal Test Procedure is fairly close. The labelling scheme did not attract much support from the vehicle industry and was eventually abandoned.

New Zealand also used to operate an import duty and sales tax regime, which imposed a heavy impost on all private vehicles and a particularly severe one on large engine sizes. The tax regime also had a strong element of favoured nation concessions and there were limits on the numbers of vehicles that could be imported. The high import taxes also afforded some protection to the domestic assembly industry as there was a higher tax on fully built-up imports (FBUs) than on completely knocked down (CKD) packs. In addition, regulations constraining hire purchase agreements made the cost of acquiring new vehicles very high, which ensured that vehicles had a high resale value and, together with the favourable climate, vehicles were very long lived. It was not unusual for late model used vehicles to command a higher price than new vehicles because of the market restrictions.

This whole tax, duty and import control regime was dismantled as New Zealand moved to a more open market economy. The differential sales tax on engine size was removed shortly before sales taxes were scrapped altogether in favour of flat rate goods and services tax of 10% (now 12.5%) on all goods and services.

Chapter 8 "Public Policy Options" reviews the current transport energy policy framework in New Zealand and examines a range of overseas policy measures that might have a place in this country.

2.4 Education, Training and Traffic Regulation

Energy efficiency measures depend on instruction, education, persuasion and a reliance on psychology to influence the actions of vehicle buyers and users. These techniques can be directed at all aspects of fuel efficiency improvements and can also be supplemented by incentives or compulsion (through regulation). In particular, behavioural influence can be brought to bear on:

- driver behaviour;
- vehicle maintenance;
- vehicle purchasing decisions;
- use of alternative transport modes; and
- modifying transport demand.

Driver education and training is covered in Chapter 5 "Road System and Driver Performance". The relevant section (5.3) also deals with vehicle maintenance. Providing fuel efficiency information to influence vehicle purchases is discussed in Chapter 8 "Public Policy Options", while encouraging mode switching, or a reduction in transport demand, is covered in Chapter 6 "Public Transport and Other Options".

Where behaviour modification is to be achieved by persuasion, the subject will respond better if the advice being proffered is:

- clearly in the interests of the subject;
- has the support of peer group influences;
- is supported by the government; and
- has widespread recognition as a necessary social objective.

In the late 1970s and early 1980s, when the self interest was evident in the price of fuel, there was general support for a fuel conservation ethic, and there was tangible government support through various programmes. These influences are much weaker today, although the "greenhouse effect" is having some moral influence over sections of the population.

2.5 Information and Communications Technology

Information and communications technology has been, and is expected to continue to be, an expanding field that has profound implications on the way human activities are organised and conducted. The high processing power, miniaturisation and relatively low cost of computer systems now allows optimisation processes to be carried out in real time, which previously required extensive, costly and time-consuming analysis. At the same time, communications technology has also been advancing rapidly, with the development of such systems as accurate satellite-based positioning (GPS), high capacity data transmission via optical fibre, and remote sensing using radio frequency transducers. In the field of road transport, information and communications technology has existing or potential application in:

- traffic signal control systems;
- electronic vehicle identification — for access control/prioritisation/charging;
- driver information/advisory systems;
- demand responsive vehicle scheduling; and
- automatic road vehicle guidance.

The practical application of the above technologies is discussed in Chapter 5 "Road System and Driver Performance", Section 5.2 "Information and Communication Technologies". While each of the applications are directed at improving the efficiency of transport and keeping congestion within acceptable limits, and so undoubtedly have energy efficiency benefits, there appears to be little information available on the scale of fuel efficiency improvement each is likely to deliver.

2.6 Alternative Fuels and Energy Efficiency

During the 1975-1985 period, New Zealand expended considerable research and development resources on alternative fuels to petrol and diesel with the aim of increased self-sufficiency. The final report of the Liquid Fuels Trust Board (1990) summarises government efforts. Alternative fuels investigated and developed comprised:

- compressed natural gas (CNG, mainly methane);
- liquefied petroleum gas (LPG, mainly propane);
- methanol, ethanol and higher alcohols as fuel extenders and high percentage blends;
- animal and vegetable oils as substitutes for diesel; and
- a limited investigation into electric vehicles.

These fuels were researched from the perspectives of availability and sources of supply; technical modifications required to vehicles and their operability; and implementation, marketing and public acceptance. The NZERDC was also involved, mainly in regard to the promotion and development of CNG use and the economics of production of fuels from biomass.

As a result of these efforts, New Zealand became a leading nation in the implementation of LPG and CNG fuels programmes, and a gas fuels industry developed as a result that is still active today. However, while New Zealanders are active in assisting overseas governments in the development of alternative fuels programmes, it is ironic that at the same time the usage of CNG and LPG as transport fuels within New Zealand has been falling.

The objective of the alternative fuels programme was national energy self-sufficiency, and energy efficiency gains in terms of useful work achieved from the chemical energy content of the fuel used, compared with the fuel substituted, was not the primary objective of this development effort. However, the results of the many fleet trials of vehicles converted to operate on alternative fuels showed that small gains in energy efficiency were possible and, if vehicles are converted to dedicated operation on the substitute fuel, efficiency gains of 10% to 15% were achievable.

While the climate of public concern about energy supplies in the late 1970s and early 1980s allowed CNG and LPG to be introduced, this was accompanied by some compromises, at least in the case of CNG, in the use of the vehicle and the rather variable performance of the conversions.

Modern developments in alternative fuels and engine systems are reviewed in Chapter 4 “Alternative Fuels and Engine Systems”. This chapter considers a range of alternative fuels, not just CNG and LPG. It covers electric vehicles as well as those with heat engines.

2.7 Alternatives to the Private Car

Alternative forms of transport to the conventional private car include micro cars and public passenger transport.

Urban public transport in New Zealand is provided mainly by stage bus services, although in Wellington and Auckland there are also rail services, and for some of the smaller centres bus transport is now provided by small passenger vehicles run by taxi companies. While there has been interest in developing other forms of urban public transport such as light rail/street tram, so far there has been no commitment to funding such systems (other than tourist ventures such as the Christchurch tramway). However, bus priority measures on certain roadways have been introduced to a very limited extent. Facilitating public transport is discussed in Chapter 6 “Public Transport and Other Options”.

Given the dominance of private vehicles in providing for passenger transport demand, alternative smaller forms of private transport to the conventional 4/5 seater passenger car offer a potentially large market for energy efficiency. These alternatives include “micro” cars designed to carry one or two people, motorcycles and mopeds, and bicycles. In terms of advanced technology and cost, there is a wide range of options between the latest “concept” urban vehicles under development by various automobile manufacturers to the mundane, but highly energy efficient and cheap push bike. Alternative forms of private transport are also discussed in Chapter 6.

2.8 Improving the Energy Efficiency of Road Public Passenger Transport

General Scope for Energy Efficiency Gains

Opportunities for improved energy efficiency in road public passenger transport, as with the private car, stem from technical improvements in vehicle design, smoothing the driving profile and by achieving higher load factors.

Road public transport vehicles include urban omnibus services, route passenger transport and taxi services. Intermediate size “minibus” vehicles run by bus and taxi operators are now in greater use than before, encouraged by changes in industrial legislation and the introduction of competitive tendering for transport services introduced over recent years.

The scope for energy efficiency gains on a national level from energy efficiency improvements within the public transport system is limited by the overall contribution of public transport to road transport fuel use — only about 6% for buses and under 1% for taxis.

Cost Structure of Public Transport Operations

Whereas fuel accounts for about 10% of the total cost of passenger car operation (refer to Chapter 8 “Public Policy Options” for an elaboration), the percentage is lower for bus transport because of the inclusion of the driver‘s wage costs and the overheads of administering the system. The labour cost component of public transport can be quite influential in how the services are provided. High wage costs lead to strategies to limit staff numbers, which can be done by using larger buses and less frequent services. These large buses continue to be used in periods of low demand at low load factors and low energy efficiency. It is notable that small buses are more prevalent in low wage economies, particularly where owner-drivers are employed. Taking this point to its extreme, driver costs are lowest when one of the passengers takes on the driving task for no reward. This occurs in car and van pooling arrangements.

Deregulation and Competition

As in other parts of the transport system, labour award conditions have presented barriers to change and subsidised local-authority-run bus services did not have the discipline of competition and the requirement to run at a profit. The effect of deregulation and competition on energy efficiency in public transport is two-edged. The resulting competition encourages innovation and price differentiation.

Disadvantages of this increased competition are that bus services can become more fragmented through the introduction of new operators and the services subject to more frequent changes, both of which lead to reduced patronage. This implies the need for effective public information systems so that those choosing or having to use public transport know where and when the services are running. This point is emphasized in parts of Chapters 5 and 6.

Planning the Public Transport Network

The public transport systems in most cities are based upon scheduled stage services. Route planning for these services is undertaken to best serve the passenger demand based on market surveys. Most often, it is the patronage surveys carried out by the operator or the regional transport planning authorities that are used for future service planning and these can only gain information on routes already being run. Wider ranging surveys of household travel patterns are rarely undertaken, but do provide a better basis for planning comprehensive service changes. There is possibly some scope for better optimising route service planning so that the frequency, size of vehicle, location of bus stops and routing of the stage bus system is the best match to demand.

Demand-responsive Systems

Demand-responsive public transport has had only limited application, although its potential has been debated for many years. It relies upon riders registering their request for transport with a control centre and the centre allocating a vehicle to pick up and set down the passenger door-to-door. The concept is in practice in New Zealand in a limited way as airport shuttle bus services and shared taxi arrangements, normally on a “one-to-many” pattern of origin/destination. Conceptually, a fully demand-responsive public transport service would also operate “many-to-many”. The key to demand-responsive services lies in communications technology and in real-time optimisation of vehicle fleet control. Paratransit, an emerging flexible public transport option, is discussed in Sections 5.2 and 6.2.

The energy efficiency improvements from demand-responsive systems comes through load factor improvements and attraction of riders from private transport.

Bus Scheduling and Information Systems

An inherent problem in running a scheduled bus service is keeping to timetables and the tendency of buses to bunch. Bunching is a natural tendency, as a slight delay in bus arrival leads to more passengers waiting at the bus stop, longer boarding times and further delay. Despite best attempts, it can be difficult for bus drivers to run to time. However, reliability in the timetable is one of the most critical service factors valued by passengers, and removing uncertainty over when the next bus is going to arrive and whether there will be space on it when it does arrive would be a useful service improvement.

Communications technology can assist in this process and there are a number of examples overseas where display systems at bus stops are being used to advise passengers of bus arrivals in a similar way that urban metro systems have done for years. Systems of this type are also being used to help bus operators to better control the fleet on the road. Further details are provided in Chapter 5 "Road System and Driver Performance".

Taking the process further, on-line passenger information systems can be extended to give information on bus routes, advice on trip planning and likely travel time, and warning about points of congestion on the system. Public VDU terminals for the purpose can be located at secure locations along the transport route or, conceivably, could be accessed from personal portable communications units such as a pocket computer or a cellphone.

The energy efficiency gains from these innovations would be indirect and would arise from the enhanced performance and, therefore, the competitiveness of the bus system attracting riders from less energy efficient modes of transport.

Bus/High Occupancy Vehicle Priority

Giving special priority access for buses and other high occupancy vehicles, whether public or private, is a way of encouraging ride sharing in private transport and improving the service level of public transport. As bus priority seeks to minimise vehicle delay, there are also energy efficiency gains through smoothing the vehicle driving profile and reducing idling fuel consumption.

Peak hour bus and carpool reserved lanes have been used in New Zealand to some extent, e.g. the northern approaches to the Auckland Harbour Bridge.

Other obvious improvements to public transport would have the same effect. These include upgrading terminals, refurbishing vehicles, etc.

Alternative Urban Public Passenger Transport Systems

There is a wide range of urban transit systems in use around the world, from high passenger density heavy rail (metro) through to the conventional bus. There is a corresponding gradation in capital cost, in the passenger density required to support the system and in the flexibility to change the service to changing patterns of demand.

With the exception of Wellington, New Zealand cities are low density with fairly low corridor passenger flows and a substantial proportion of travel associated with suburban centres and cross-town movement. By and large, as in other countries, fixed public transport systems are best suited to commuter travel between the CBD and the residential suburbs.

The main urban centres are in the process of conducting reviews of their urban transport planning studies and some alternative public transport systems have been considered. In Auckland, there is interest in some quarters to establish a light rail system that uses existing suburban rail track with extensions onto city streets in the CBD. Another system, more easily introduced, is a busway to serve the North Shore, which has now been established. Busways may be conventional roadway reserved for bus use or guided systems, which use guide rails that allow a narrower track (O-bahn system).

2.9 Urban Planning and Demand Management

Energy efficiency can be included as an objective of urban land use and transportation planning policy. Over the long term, changes in urban form can be encouraged or imposed through planning controls. A number of European cities have used strict density controls to reinforce transport demands along corridors to suit the development of mass transit systems. However, to be successful, such plans have to be followed persistently over a long period of time and for this reason must obtain a high degree of public acceptance. It is debatable whether New Zealanders are willing to let themselves be organised in such a disciplined fashion.

In the short term, many cities overseas are turning towards positive management of transport demand within congested urban networks. Problems are particularly acute in cities established prior to the industrial revolution where ancient street systems, often based on radial patterns and with very limited space for roadway, cannot accommodate the number of private vehicles generated by high levels of vehicle ownership.

As information and communications technology has developed, more sophistication has been introduced into the control of roadspace and parking within the urban area. Many cities already control access to their central core, but technology will now allow more precise pricing for road use according to the delay imposed on the system by vehicles entering the controlled area.

Chapter 6 "Public Transport and Other Options", Sections 6.4 and 6.5, cover urban planning and transport demand management respectively.

2.10 Improving the Energy Efficiency of Road Freight Transport

Apart from vehicle design technology and retrofit equipment to improve the fuel efficiency of freight vehicles, opportunities for increased energy efficiency in the freight transport system lie in the use of larger vehicles, measures to improve overall load factor and better integration of road freight with other freight modes, in particular rail.

Energy Efficiency and Vehicle Size

The energy efficiency and economics of road freight transport is very much a function of vehicle size. All else being equal, large trucks are more efficient in terms of energy use per tonne-kilometre than small trucks. Over the years, country standards for permissible gross weight, axle load and dimensions have gradually increased. In New Zealand, the maximum combination weight of 39 tonnes and overall length of 19 metres can now be exceeded for certain rig configurations that can demonstrate the required manoeuvrability and acceptable wheel and axle loading. There have been suggestions that certain main highways be improved to a higher standard of pavement construction so that the road freight industry can take advantage of the economies of heavier vehicle loads.

Improving Truck Load Factors

In general, the smaller the vehicle, the lower the average load factor. Large trucks are expensive to run and operators do their best to keep the load factor high, although some types of operation are, by their nature, full outward/return empty.

For the general carriage of goods, greater freight consolidation could possibly be achieved by the introduction of freight brokering, an intermediary between the shipper and the truck operator who would match freight demand with available capacity. Any overall increase in load factor would provide financial benefits for the operators and customers and would also improve energy efficiency.

Inter-modal Economies

Each freight transport mode best serves certain parts of the market. For example, rail is more efficient than road as a carrier of bulk goods over long distances. The advantage of rail increases for all commodities as distance increases, with the exceptions of highly time dependent, perishable or fragile cargo. If the interface between rail and road can be streamlined, then more freight would be able to take advantage of the greater fuel efficiency of the rail system on line haul operation.

Further information on road freight and other freight modes can be found in Chapter 7 "Road Freight, Rail, Sea and Air Transport".

Chapter 3
Vehicle Technology

3.1 Introduction

This chapter covers emerging technologies that will make motor cars more efficient in the future. The basic principles and technologies outlined are also relevant to other motor vehicles, such as light vans, buses and trucks, and some information pertaining to these vehicles is presented. Some of the energy efficiency principles in this chapter may also be relevant to other transport modes, such as light rail or air transport.

This first section covers some introductory issues. Section 3.2 looks at the impact of driving conditions on fuel consumption. Building on this information, Section 3.3 identifies strategies for improving the fuel efficiency of cars, and subsequent sections outline the key technologies. Section 3.10 provides an overall assessment of the technologies and their potential for improving motor car fuel economy.

Ultimately, the net effect of applying a range of new technologies to cars and light vans could be a 50% to 75% reduction in fuel consumption. An improvement of this magnitude could be more than a decade away, however. The relatively affordable price of petrol and diesel and the commitment of manufacturers to incremental development of current technologies and production methods may slow progress. Nonetheless, there are many economically attractive opportunities for research and development, the results of which could push along the demand for very efficient vehicles.

Opportunities for New Zealand

New Zealand is widely seen as a receiver of vehicle technologies rather than an innovator or developer of new technologies. The country has only a small vehicle assembly industry and support infrastructure. Development of vehicle technologies is presently dominated by overseas corporations, some with research budgets that exceed the total public expenditure of the New Zealand government.

It would be a mistake, however, to think that New Zealand enterprise has no role to play in developing vehicle technologies. In the past, New Zealanders have developed kit vehicles and components. Modern automobile design involves the integration of a wide variety of technologies: electronics, materials science, thermodynamics, aerodynamics, etc. This chapter will show that there are many opportunities within the technical and financial capabilities of New Zealand firms to develop technologies that could play a role in the cars of the future.

Optimistically, there is a possibility of future New Zealand vehicle design and prototype testing (and perhaps local assembly using a balance of overseas and local parts). The main technology that could open up this possibility is the use of fibre-reinforced plastic parts that avoids the need for the expensive tooling and massive production runs required to economically produce steel car bodies. For example, the expertise on exotic materials developed by the New Zealand boat building industry could provide a starting point for a greater New Zealand role in vehicle design and manufacture.

Consumer Attitudes

While fuel efficiency has its place in the objectives of the automotive engineer, at present it has a relatively low priority in the requirements of the car purchaser. Above fuel economy come:

- performance;
- style and image;
- reliability and low servicing costs; and

- increasingly, vehicle safety.

Performance and vehicle safety generally run against fuel economy. Engines tend to be oversized to provide greater acceleration. Safety is perceived to be associated with heavier vehicle construction, whereas weight reduction helps to reduce fuel consumption.

Pollution Control Issues

Pollution control is still a relatively low priority in New Zealand, but is increasingly important overseas. Better emission control is consistent with better economy insofar as it implies more complete combustion of the fuel. However, exhaust control systems affect the back pressure and thus the thermodynamic efficiency of the engine and there is something of a trade-off between economy and high emission standards. In addition, standard three-way catalytic converters require the engine to operate at stoichiometric conditions (the exact air/fuel ratio for complete combustion) and not the more fuel-efficient lean-burn setting (see Section 3.4).

The introduction of unleaded fuel also carries a penalty in reducing the octane rating, the measure of the engine's propensity to avoid "knocking" (irregular detonation of the fuel/air mixture). This problem can be avoided by lowering compression ratios, but this introduces a potential fuel economy penalty. The strategy currently being adopted, that of using special additives in place of lead to maintain compression ratios, is controversial since there is concern over the carcinogenic properties of these additives.

3.2 The Effect of Driving Conditions

Fuel Consumption Modelling

Vehicles are driven under a wide variety of conditions that impact on fuel consumption. The varying response of vehicles to different conditions provides some guide to priorities for technological improvements. There is a considerable history of mathematical modelling of motor vehicle fuel consumption in relation to vehicle design and road conditions. Some models concentrate on the energy relationships within the vehicle system for the purposes of distinguishing the fuel consumption characteristics of different design features of the engine and transmission. Other models are more concerned with how the fuel consumption of a typical vehicle or a typical mix of vehicles varies with road and traffic conditions.

When evaluating road and traffic improvements, Transit New Zealand has adopted the fuel consumption models developed by the Australian Road Research Board (ARRB,) which are of the second type. The ARRB's latest ARFCOM model for light and heavy vehicle fuel consumption under both urban and highway driving conditions represents one of the most detailed mathematical representations of fuel consumption in relation to traffic conditions. However, at a more general level, the fuel consumption of a vehicle over a length of road can be simply modelled by a function of the form:

Fuel litres/100km, $F_d = a_0 + a_1 / V + a_2 V^2$

where V is the average journey speed. While not as precise as the more detailed ARFCOM model, this empirical relationship, first reported by Everall (1968), has proved to be a good guide. The curve relating fuel use and average speed is shown in Figure 3.1. Fuel consumption is high at low journey speeds which corresponds to urban conditions with a high proportion of stopping and starting. A minimum fuel consumption occurs around 60 to 70 km/h average journey speed, which would apply more to rural roads (average journey speeds in New Zealand urban/suburban areas are generally around 35 to 40 km/h inclusive of stops). At higher speeds, fuel consumption starts to rise.

The three coefficients in the equation correspond to:

a_0 which can be associated with the energy used to overcome inertial resistance and part of rolling resistance, and is proportional to vehicle mass and the thermal efficiency of the engine under load.

a_1 the time-dependent component of fuel consumption, which can be approximated to the zero load or idle fuel consumption rate.

a_2 the aerodynamic resistance and a small component of rolling resistance.

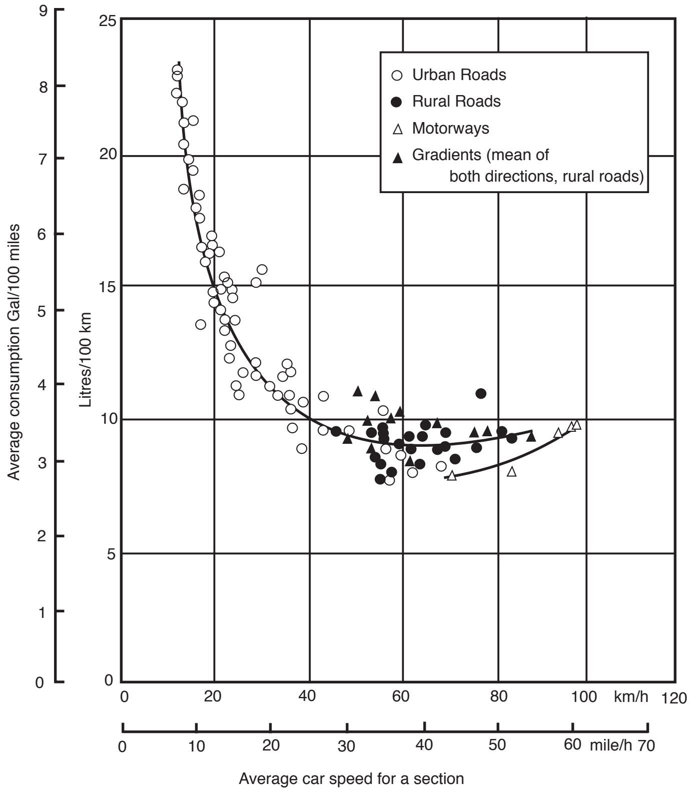


Figure 3.1: Variation of fuel consumption for an average car (Everall, 1968)

For urban conditions, the third term is negligible and it is, in fact, possible to estimate the fuel consumption with reasonable accuracy purely from a knowledge of the traffic composition, typical mass for each vehicle type and idling rates of fuel consumption. In addition to stop-start driving, slow average speeds for a journey can be indicative of a considerable time spent at rest with the engine idling. Zero load fuel consumption, that is at rest or while braking, can be a significant component of overall fuel use per kilometre.

The data in Figure 3.1, which shows the fuel consumption versus average speed, needs to be interpreted with care. For example, it gives a false impression regarding the benefits of traffic calming; the figure indicates that the increase in fuel use as speed falls from 50 km/h to 30 km/h can be as much as 40%. Studies of traffic calming indicate a much smaller change in fuel consumption. One study (Pharoah and Russell, 1989) suggested a 7% change depending on driving style — a 7% increase in fuel use for drivers who use second gear to accelerate between obstructions and a 7% decrease for drivers who use third gear and maintain a reasonably constant speed. As mentioned above, the slow average speeds in Figure 3.1 are indicative of stop/start driving and idling rather than a calmed, smooth flow.

Curves of fuel consumption versus speed for steady speed vehicle operation are more relevant to the traffic calming situation. Figure 3.2 shows a representative case. In this example, the discontinuities are gear change points, which are, of course, rather vehicle specific. These curves show a similar U-shape to those in Figure 3.1, but with the effects of stop/start cycles removed, the minimum fuel consumption point is a little lower, around 40 km/h to 60 km/h, and the rise in fuel consumption at speeds over 80 km/h is more pronounced and the rise at speeds below 50 km/h (for cars) is only slight.

The results of studies into the effect of driving conditions on fuel use indicate that there are two broad approaches to reducing the energy consumption of vehicles during urban driving:

- manage urban traffic so that it is smooth flowing and the journey times are close to those that would be obtained if vehicles travelled at their optimal speed; and
- improve the inherent energy efficiency of the vehicle by reducing its weight, improving engine performance and recovering braking energy.

The first approach involves driver education, better traffic control and intersection design, and other steps to reduce urban traffic congestion, such as greater use of public transport. Rural road or arterial road alignment can be improved to increase sight distances, to avoid sharp bends (and hence loss of momentum) at the base of inclines, etc.

The second approach is related to the technology of the vehicle. Section 3.3 looks more closely at the issue of vehicle efficiency, during both urban and highway driving, in order to further clarify the importance of engine design and vehicle mass and to identify other technology improvement strategies.

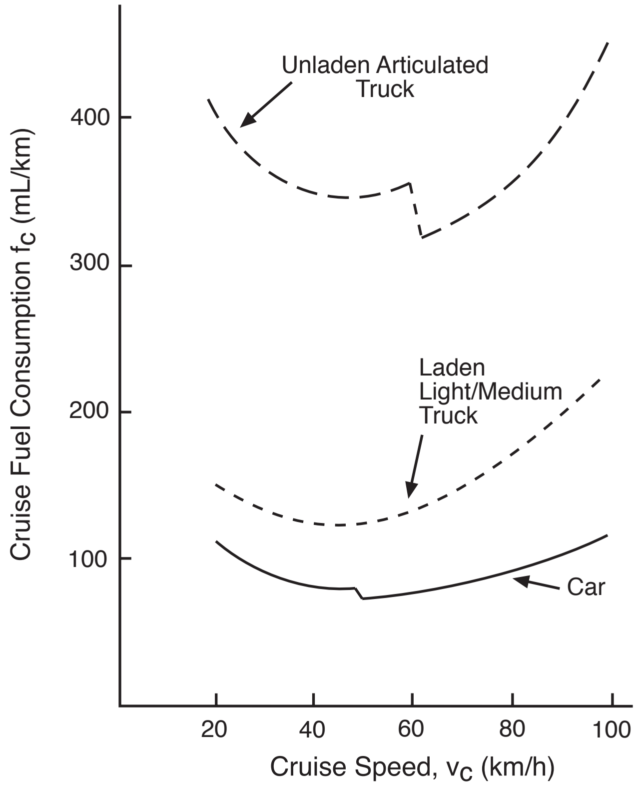


Figure 3.2: Fuel consumption at steady cruise speed for various vehicles

3.3 Strategies for Improvement

Introduction

The fuel consumed by a motor vehicle depends upon aspects of its design and, as indicated above, the duty cycle over which the vehicle is driven. Conventional road vehicles are normally powered by an internal combustion engine and vehicle motion is produced through the frictional reaction between road wheels and the road surface. Within the vehicle system, the chemical energy content of the fuel is converted to useful work at the wheels by the mechanical pressure of fuel/air combustion within the engine transmitted mechanically through the vehicle drive train.

There are limits to the efficiency of this conversion imposed by the engine's thermodynamic cycle itself, and the losses through incomplete combustion of the fuel, through mechanical friction in the drive train and hysteresis losses in the deformation of the tyres. In addition to incomplete combustion resulting in hydrocarbon emissions at the exhaust, there are fuel losses from leaks and spills of liquid fuel and vapour between the service station pump and the engine intake. The thermodynamic losses result in heat rejection from the engine, giving rise to the need for a cooling system, which itself absorbs energy through a water pump or fan, while the mechanical losses in the drive train are also converted to heat and minimised by mechanical lubricants. The losses within the vehicle system are influenced considerably by the environment, particularly cold starting in low temperatures. Figure 3.3 shows the various pathways for the loss or dissipation of fuel energy from a car's petrol tank (derived from Lovins, 1993, and Mendler, 1992).

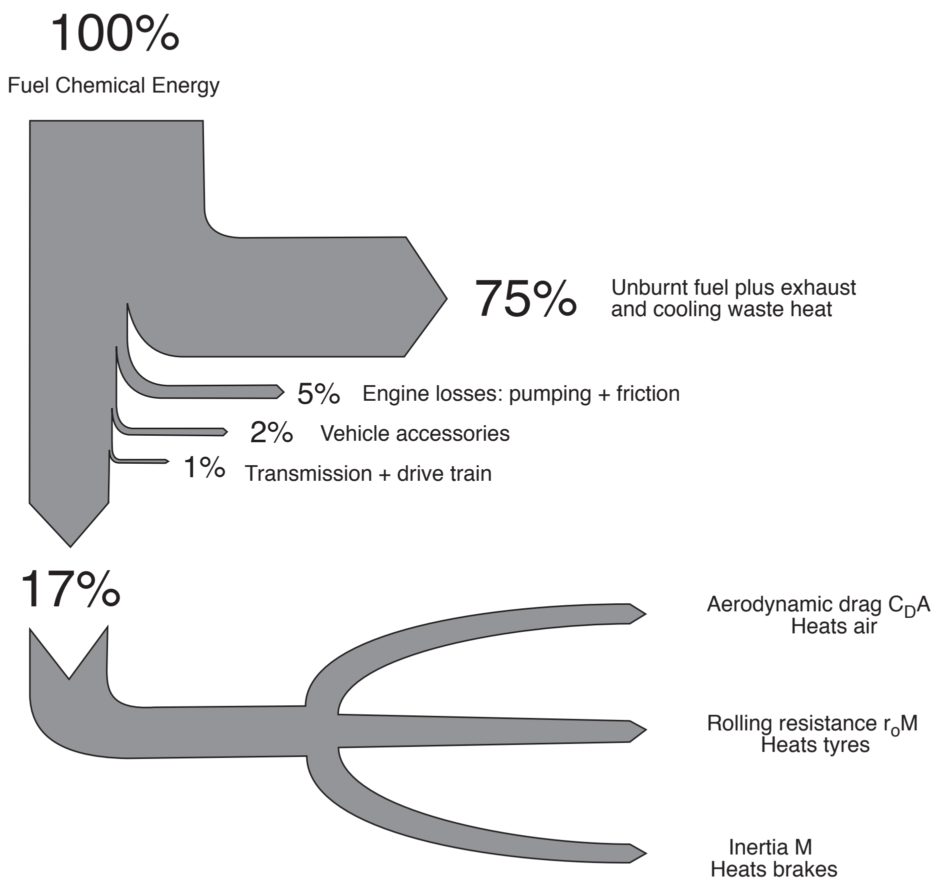


Figure 3.3: Motor vehicle energy losses

Energy Conversion

In a typical production internal combustion engine, 80% to 85% of the energy content of the fuel is lost before it gets to the driving wheels. Engine and transmission friction and pumping losses (e.g. cylinder aspiration) account for part of the loss. This will generally vary between 5% and 7.5%. Most of the loss occurs as waste heat from the cooling and exhaust systems. Only around 25% of the energy content of the fuel is converted to work. While this can be increased, the thermodynamics of the four-stroke cycle limits maximum efficiency to less than 40%. Improving the thermodynamic efficiency of car engines and developing new types of engines has been the subject of intense research and development. However, there are still a large number of efficiency options that remain to be refined and applied. It may be possible to recover and reuse some of the waste heat inevitably generated from even very efficient engines. This waste heat could be used to drive such accessories as air conditioning. Motive power is currently used to generate electricity for vehicle accessories, to power the cooling fan and to drive the air conditioning system etc. There is little data on the energy demands of these accessories, but they could account for 10% to 15% of engine power.

Energy Dissipation

During free-flowing urban driving, of the 15% to 20% of fuel energy that gets to the wheels, about a third is used to overcome air resistance, a third is used to overcome rolling resistance and a third is dissipated in braking. In plain terms, the energy is lost by heating air, tyres and brakes. On the open road, overcoming air resistance becomes the dominant energy requirement. It is useful to explore these losses a little further in order to identify the vehicle parameters that could be managed to improve efficiency.

Once the mechanical energy is delivered to the road wheels, this is absorbed by the various forces opposing motion, which are:

- inertial acceleration and deceleration;
- gravitational force — hill climbing;
- aerodynamic drag; and
- rolling resistance — tyre and road.

The relative contributions of these four forces to overall fuel consumption varies according to the nature of vehicle use. In urban running, inertial effects are at their highest, absorbing up to 50% of energy, with fuel consumption closely related to the number of stops and starts and to the evenness of the traffic flow. For highway driving, aerodynamic drag becomes much more important and dominates at high speeds, where it can absorb up to 60% of energy delivered to the road wheels.

The contribution of climbing resistance can be as much as 70% of the fuel consumption for low-speed operation in mountainous terrain. However, the bulk of vehicle travel is either within urban areas on flat to moderate gradients or on main highways, again where gradients tend to be flat to moderate. Exceptions to this generalisation occur in such places as Wellington city or Dunedin.

Inertial acceleration and deceleration and gravitational forces are directly proportional to vehicle mass. Vehicle efficiency could be improved if either weight was reduced or inertial and gravitational energy could be recovered for reuse. Rolling resistance is also directly related to vehicle mass as well as the number and diameter of the wheels and the nature of the road surface. For any given wheel load, diameter and road surface, tyre design features can influence rolling resistance. Aerodynamic drag is a product of the vehicle body shape and frontal area.

Energy Recovery

Conventional motor vehicles powered by internal combustion engines make little attempt at energy recovery. In theory, the energy expended in hill climbing and acceleration (net of any aerodynamic and rolling losses) is available for recovery on downgrades and when braking. Regenerative braking requires that an energy storage system be added to the vehicle, such as a generator/alternator and electric battery, mechanical storage in a flywheel or a pneumatic system. However, the benefits of such systems have to be weighed against the costs from extra on-board mass, and the additional capital and maintenance expenditure.

Effect of Vehicle Age

Waters (1990) showed a linear deterioration in car fuel economy against accumulated mileage amounting to 13% over 80,000 km, that is 1.6% per 10,000 km of travel. Most of the cars in New Zealand are of Japanese origin and may not experience the same rate of deterioration as United States vehicles. This deterioration is a result of wear in the engine and drive system, which opens up tolerances between moving parts. The deterioration of engine performance with age is being recognised in public policies on air pollution control. Present and future vehicle emissions standards in California, for example, relate to vehicles after they have driven 50,000 miles (80,000 km).

Key Improvement Strategies

The following steps appear to be critical to radically improving the fuel efficiency of vehicles:

- improve engine efficiency;
- recover/reuse waste heat;
- reduce accessory loads;
- reduce vehicle mass;
- lower air resistance;

- recover braking energy; and
- reduce tyre rolling resistance.

These steps need to be addressed in an integrated manner. Installing energy recovery systems (such as regenerative braking and flywheel or battery energy storage) could add mass to a vehicle. However, if flywheel energy was available to boost vehicle acceleration, then a smaller and lighter engine may be satisfactory.

Arguably the most important step at this stage in the development of the motor car is to reduce body weight (but not at the expense of passenger safety). This will allow a positive feedback through smaller engines and lighter suspension systems. Waste heat recovery and improved engine performance may then follow in importance. Recovery of braking energy is also strategically important but may only be practical on electric and electric-hybrid vehicles. The most tricky step, due to potential performance trade-offs, and arguably the one that will confer the least benefits, is markedly reducing rolling resistance for cars. This could, however, be an important issue for heavy vehicles.

3.4 Engine and Transmission Systems

Introduction

This section outlines a number of potential improvements to the petrol four-stroke engine, the most common engine used in cars and light vans in New Zealand. It also discusses transmission improvements that could apply to vehicles powered by various types of internal combustion engines. The use of diesel and other alternative fuels in four-stroke type engines is discussed in Chapter 4 "Alternative Fuels and Engine Systems". Electric and hybrid vehicles are also covered in that chapter.

While presently little used, two-stroke engines could become more common in motor cars as their disadvantages are overcome. Other engine cycles, such as various forms of rotary engine and ceramic gas turbines, etc., may also take a share of the motor vehicle engine market in the future. Two-stroke and other non-electric alternatives to the four-stroke engine are also covered in Chapter 4.

Current Situation

The efficiency of conversion between fuel supply and engine-shaft delivered energy has been markedly improved over recent years by the application of electronic management systems. This technology and other design improvements more precisely deliver the optimum quantity of fuel into the chamber at the right time, more evenly vaporise the charge and ensure complete combustion and subsequent purging of the cylinders. Electronic management of charge delivery and ignition timing is now commonplace on new vehicles with the mechanical carburettor being phased out as older vehicles are retired. Notwithstanding this improvement, car engines do not operate very efficiently compared to stationary engines, cogeneration plant etc.

Automobile engines must operate over a large power range, from approximately 6 kW on average for combined city and highway driving to 100 kW during maximum acceleration. The efficiency of the engine varies significantly across this power range. Unfortunately, at average loads the efficiency is approximately 17%, while the peak efficiency of over 30% is usually only achieved (if at all) while driving at highway speeds in the higher gears. Technologies are being developed to enable the low load efficiency to increase to over 25% (Mendler, 1992). This increase is equivalent to a 47% improvement in fuel efficiency from engine technology.

Strategies for Improvement

Figure 3.4 is a typical engine output map showing engine efficiency contours versus engine RPM together with a few constant power curves (steady urban load, 5 HP; highway load, 12 HP; and average load, 8 HP) and performance curves for different gears. The vertical axis on Figure 3.4 is average cylinder pressure (BEMP). For a given engine speed and gear selection, BEMP can vary depending on instantaneous throttle setting. The data shown is for steady-state conditions and maximum efficiency for the gear-speed combination. The maximum capacity of the engine is 135 HP (around 100 kW). Note that 1 HP is approximately 0.75 kWh. The figure shows that even with the use of a fifth gear (normally available on modern cars), the vehicle will rarely be operating close to its potential, the 33% island efficiency. The dashed line in Figure 3.4 represents the performance of a continuously variable transmission, which is discussed shortly.

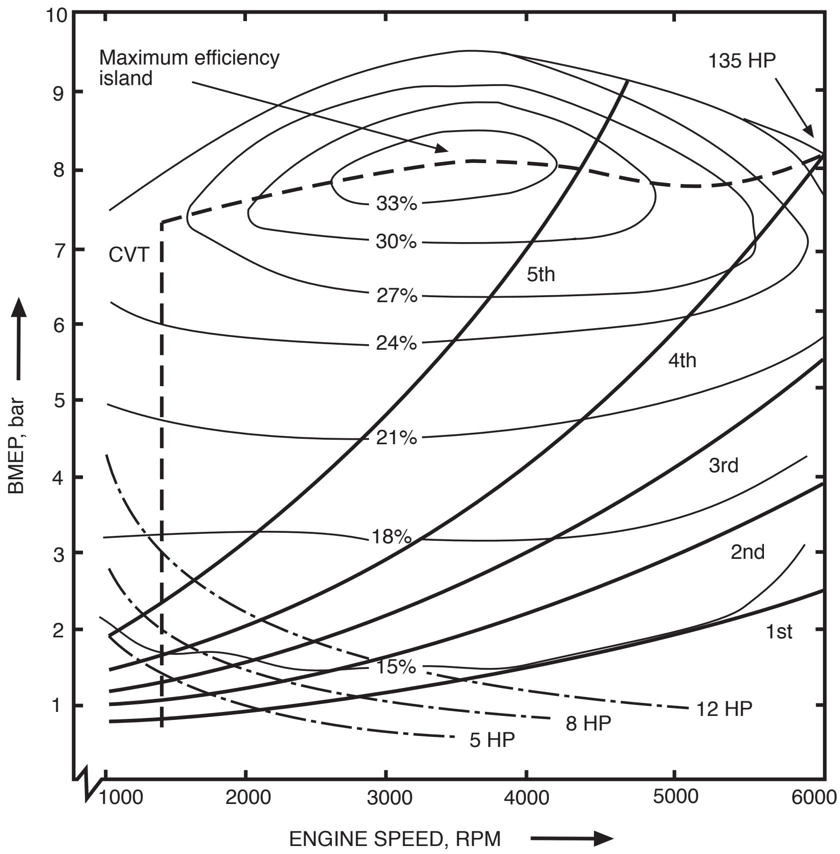


Figure 3.4: Engine performance map — typical car engine (Mendler, 1992)

Most urban driving is done in the first four gears, at less than 3,000 RPM where the efficiency is below 18%. Given normal variable speed, stop-start driving, there are four strategies to improve the engine's efficiency:

- increase the size of the maximum efficiency island;
- increase the height of the island, i.e. the maximum efficiency;
- shift the island to lower power levels where most driving occurs; and
- stay on the island through a greater proportion of the driving cycle.

A range of technologies, generally referred to as variable control systems, are available to meet these strategies:

- fuel supply shut-off;
- variable valve control;
- lean burn engines;
- variable compression ratio; and
- advanced transmissions.

Advanced transmissions are a response to using variable compression ratios. Another approach is to move to a smaller engine. However, unless there is an additional power source to augment the main engine, acceleration and top speed may be compromised. Electric-hybrid engines attempt to deal with this issue and are discussed in Chapter 4.

Another way to improve engine efficiency is ensure that the engine is at its operating temperature before startup. This can be achieved via waste heat recovery and reuse. Waste heat can also be used to power accessories, such as air conditioning. Heat recovery and reuse is discussed in Section 3.9. The five technologies listed above are briefly outlined below. For more detailed information on these technologies refer to Mendler, 1992 and Archer, 1992.

Fuel Supply Shut-off

A considerable quantity of fuel is used when the engine is not delivering power, either when at idle when stationary or in deceleration mode. Consequently, a system that shuts off the fuel supply in these modes and restores it (together with ignition) when power is demanded will, in theory, save fuel. Volkswagen describes how such a system installed in a diesel car gave a 15% economy improvement under road test conditions (Neumann, 1990). If complete engine shut down is used, then starter motor loads may mean heavier batteries. There may also be safety concerns over having the vehicle parked in traffic without the ability to immediately move.

Variable Valve Control

In spark ignition engines, engine power is controlled by throttling the air intake. The resultant turbulent air flow adds to pumping losses and causes a drop in engine efficiency. Figure 3.5 shows that pumping losses vary with engine load. At high loads, they are quite small, but most driving is done under low load conditions where they can reduce potential usable power by 20% or more.

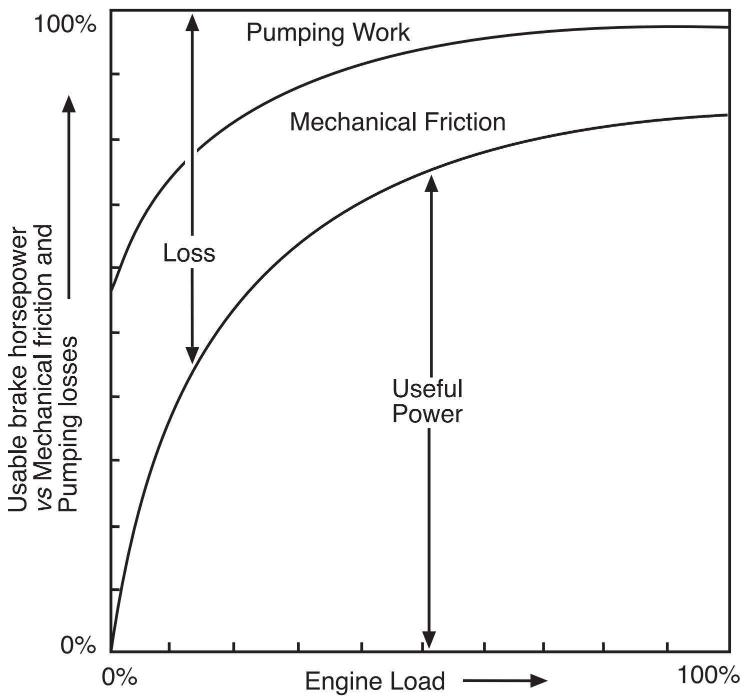


Figure 3.5: Usable power versus friction and pumping losses — typical car engine at low RPM (Mendler, 1992)

An alternative method of engine control is variable valve control (VVC). VVC allows the air to enter the chamber efficiently without throttling, but then closes the valve smartly once the desired amount of air has been inducted. In other words, at light loads a smaller bite of air is taken, but taken efficiently. Studies have shown that running an engine at wide open throttle and using VVC to alter power output would improve overall fuel efficiency by 20% (Mendler, 1992). Honda have developed an engine with a degree of VVC (see below).

Lean Burn Engines

Spark ignition engines burn a stoichiometric fuel-air mixture consisting of one part fuel to 14.7 parts air on a mass basis. Engine efficiency can be improved by raising the air content of the mixture. Unfortunately, catalytic converters cannot reduce NO_x emissions in a lean exhaust stream. NO_x production increases as the air:fuel ratio rises to around 17:1, but then falls to very low levels at ratios above 20:1. An appropriate strategy would be to design a system that operated at either 14.7:1 where the catalytic convertors work well, or at over 20:1 where NO_x is not a problem, and nowhere in between.

A further problem is that combustion of very lean mixtures can be unstable and incomplete. Honda has addressed this problem in its VTEC-E engine by using a stratified charge in the cylinder. A small zone of near-stoichiometric mix is created in the centre of the cylinder near the spark plug to facilitate stable combustion. The outer mix is very lean. This stratification is achieved by using variable and differential valve timing between the two intake valves. This system goes some way towards VVC, but the limited flexibility of the system means that throttling still occurs. Nonetheless, Honda estimate that pumping loss reductions increase fuel efficiency by 2.5%. The main gain, a further improvement of 5% to 10%, comes from the ability to use very lean mixtures.

Variable Compression Ratio

The higher the compression ratio, the greater the thermodynamic efficiency of the engine (however, knocking will result if the compression is too high for the fuel being used). With spark ignition engines at low loads, less air enters the cylinders and the compression ratio falls dramatically. This fall would have a detrimental effect on fuel efficiency except that it is offset to a large degree by the fact that the expansion ratio does not change. Nonetheless, the low load efficiency could be improved by over 30% if the compression ratio could also be held constant.

Variable compression ratio (VCR) engines are still in the research phase. VCR hardware effectively changes the size of the combustion chamber in response to engine load. Volkswagen has achieved this using a secondary chamber, connected to the primary one, with a piston in the secondary chamber that alters its volume (Neumann 1990). Ford of England are developing a similar system. Figure 3.6 shows the basic cylinder head arrangement.

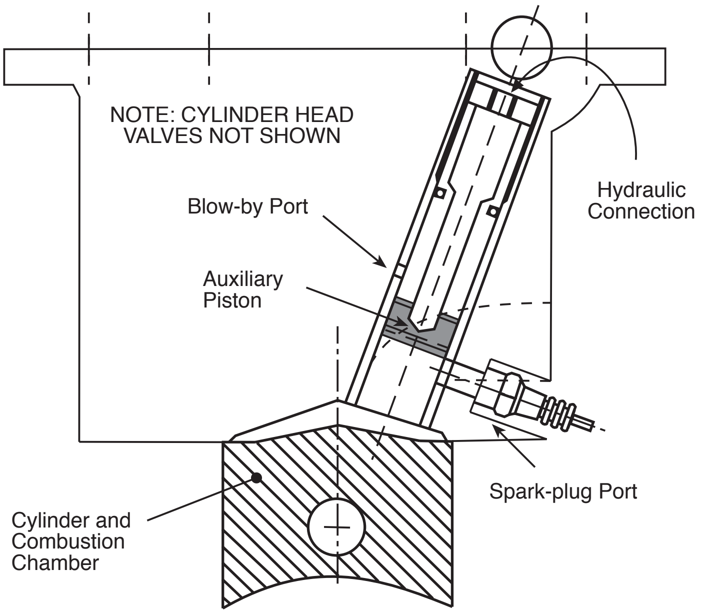


Figure 3.6: Auxiliary piston to adjust compression ratios (Reprint from Blakey, 1991, reported in Mendler, 1992)

An alternative approach is to shut off one or two cylinders at part load, but this has vibration and transmission system implications that still remain to be resolved.

Advanced Transmissions

The vehicle transmission system transfers mechanical energy from the engine to the road wheels of the vehicle. Typically, it involves a manually or automatically controlled main gear box, drive shaft and axle gears. Manual gearboxes now normally offer five ratios and the manufacturer will vary the size of these and the final axle ratio depending on the performance specification of the model.

A form of transmission, for which the technology has been available for some 20 years but which has had limited commercial production, is the continuously variable transmission (CVT). Such a transmission is adaptive to the torque and power demand and varies the gear ratio to suit, allowing the engine to operate at its point of maximum efficiency. Figure 3.4 shows the performance of a CVT system (the dashed line). With a CVT, engine efficiency could be kept above 27% for most of the driving cycle.

CVTs are now offered in a limited number of sub-compact cars. For example, Subaru and Fiat are producing a belt and variable diameter pulley CVT for their relatively small Justy and Uno cars. Studies have shown that efficiency gains of up to 20% under urban driving conditions are possible with CVTs.

3.5 Lightweight Body Materials

Present Situation

For most driving cycles, the greatest component of the forces opposing motion are the inertial and grade effects — most energy is consumed in accelerating the mass of the vehicle from rest and in increasing the potential energy of the vehicle mass in ascending gradients. Consequently, by reducing the mass of the vehicle while still retaining the carrying capacity, there are significant gains to be made in fuel economy as reduced vehicle mass allows a smaller power unit to be used in relation to vehicle size.

Currently, the kerb weight of a typical new car sold in New Zealand is approximately 1200 kg. Small cars weigh around 900 kg. Manufacturers' four/five seater concept cars achieve kerb weights of 750 kg or less, with some under 500 kg (see Table 3.1).

Manufacturer	Concept Model	Mass
Volkswagen	5 Seat Auto 2000	779 kg
Volvo	4 Seat LCP 2000	707 kg
Toyota	5 Seat AXV Diesel	649 kg
General Motors	4 Seat Ultralite	640 kg
Renault	4 Seat Vesta II	475 kg
Peugeot	4 Seat ECO 2000	449 kg

Table 3.1: Concept cars — model and mass (Lovins, 1993)

Mass reduction in production cars is being brought about mainly by the introduction of high strength, lightweight metal alloys and plastics. These materials also carry with them advantages such as resistance to oxidation. However, their introduction also depends on their durability, how well they perform under impact loads, ease of repair and, above all, their manufacturing costs. Plastics have become the standard material for vehicle interiors replacing wood and metal, and are extensively used in bumpers and, increasingly, for body panels. Some manufacturers have also explored puncture-proof tyres or narrow lightweight, short-range spare tyres to save weight and space.

Achieving significant future reductions in vehicle mass requires an integrated approach to vehicle design. The consequential effects of any changes in the body and glazing, suspension, engine and transmission need to be examined. Consideration must be given to negative and positive feedbacks, not only on overall fuel consumption, but on other design considerations. Moving to sandwich foam body construction with ultra-thin metal or carbon fibre and resin skins not only saves weight but provides better insulation, thereby cutting down on airconditioning loads. On the other hand, the performance of ultra-light vehicles, their behaviour in cross winds for example, could become dependent on the number of passengers in the vehicle at the time. This negative feedback on performance would need to be addressed.

Composite Materials

Carbon fibre and resins, plastics and other net-shape materials (referred to here as composites) offer the possibility of a quantum reduction in vehicle mass. Such a reduction would allow the use of smaller engines, which could operate more often than not in or close to their maximum efficiency island. Composites are very expensive, but the cost of materials makes up only a fraction of the final cost of a car body. For a typical steel car part, 15% of the cost is for the steel and 85% is for the shaping and finishing.

Composites have a range of features that could make their use for body parts competitive with steel or aluminium, while also providing some strategic advantages (Lovins, 1993):

- For the same strength and stiffness, composites are one-quarter the mass of steel. Composites are much stiffer than aluminium and two-thirds the mass for the same tensile strength.
- The price of composite fibres is likely to fall in the future — GM's new Pyrograf production process may cut the cost of short carbon fibres by 80%.
- The mouldability of composites allows the number of parts to be cut by at least one, and possibly two, orders of magnitude, with resultant savings in design and construction costs.
- Dies and moulds for composites are much cheaper per unit of production than steel dies, and they can be quickly made and amortized, which allows quick response to technological improvements.
- Painting can be avoided by building colour into the composite, which avoids one of the costly, difficult and polluting aspects of automobile manufacture.
- Composites are durable and, if damaged, can be replaced in a clip-on manner. With careful design, they can be recycled.
- Composites open up the possibility of smaller production runs and manufacture of vehicles by medium-sized local companies using bought-in engines and other components that still require economies of scale.

In 1991, General Motors announced it had built a prototype sporty, roomy four-seater car, the Ultralite (see Figure 3.7) that could get 6.25*l*/100 km urban running and just 3.5*l*/100 km on the highway. This vehicle could cruise at a constant 80 km/hr achieving less than 3*l*/100 km (around 100 mpg) while only needing 3.4 horsepower or 2.5 kW to push air aside. The key to this performance was a combination of a low 0.19 drag coefficient and a curb mass of 640 kg. The vehicle body was constructed from carbon fibre composites.

Heavy Vehicles

The benefits of weight reduction in heavy goods vehicles appears to be well recognised by the transport industry. Bus bodies are routinely constructed from aluminium. A notable example of changes in the New Zealand trucking industry is provided by a waste disposal company that has reduced the tare weight of its tractor and trailer combinations from 22t to 14t through the substitution of alloy body construction for steel, significantly increasing the useful payload.

3.6 Aerodynamics

This section discusses the aerodynamic design of motor cars. Information on improving the aerodynamics of heavy vehicles, namely trucks and buses, is presented in Chapter 7 "Road Freight, Rail, Sea and Air Transport", Section 7.2. The aerodynamic performance of light vans can be improved by adopting an appropriate mix of the measures applicable to cars and buses.

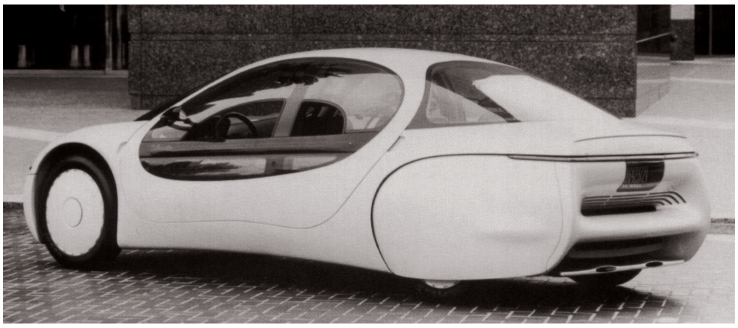


Figure 3.7: General Motors Ultralite

Historic and Prospective Improvements

The aerodynamic design of vehicles has improved greatly over the years. Aerodynamic drag is proportional to the frontal area of the vehicle and the cube of vehicle speed, with the constant of proportionality being the drag coefficient, C_D. Table 3.2 shows that values of C_D for motor cars have improved over the years, from around 0.5 in the early 1970s to about 0.3 for current models. Concept cars have achieved C_D coefficients below 0.2, so the outlook for further improvement is promising. The Spirit of Biel solar car, shown in Figure 3.8, has a C_D of 0.1. While this car has an impractical shape for a family sedan, a variety of improvements could see the C_D for ordinary cars match that of solar cars in the future.

Year	Model	C_D
1970	Average Sedan	0.5-0.6
1992	US Average Sedan	0.33
1992	US Best Sedan	0.29
1992	US Best Production 2 Seater	0.18
1992	Best Worldwide Production Sedan	0.255
1985	Ford Probe V Concept	0.137
1987	Renault Vesta II Concept	0.186
1994	Spirit of Biel - Solar	0.10

Table 3.2: Automobile aerodynamic drag data (Lovins, 1993)

Modern sedans usually have over 2.0 m^2 of frontal area. Significant reductions are possible without sacrificing interior roominess. The Honda Civic DL has a frontal area of 1.8 m^2. Among the four-seater concept cars, the GM Ultralite achieved 1.71 m^2 and the Renault Vesta II 1.64 m2.

Modern compact cars have low frontal area but are generally more difficult to streamline compared with longer vehicles. If compacts are mainly used for urban running, then their aerodynamic performance is not a serious issue. As mentioned earlier, mass is the main factor in fuel consumption when driving in congested traffic. Aerodynamics becomes increasingly important as the vehicle speed increases and is the main source of motive power loss at highway speeds.

Drag Coefficient

Knowledge on how to improve vehicle aerodynamics is not new. Volkswagen determined that the C_D of the 1921 Rumpler Tropenwagen seven-seater mid-engined car was 0.18. Significant improvements to modern sedans are possible by smoothing of the underside of the vehicle, covering the rear wheel wells and using a more compact power train to allow a more severely raked bonnet. After that, further improvements could come about by using many small surface refinements for passive boundary layer control. With aircraft, dozens of such refinements can add as much as 180 km/h of airspeed without increasing fuel use. Achieving very low drag coefficients for cars will require similar attention to detail.

Frontal Area

The other component of aerodynamic drag, frontal area, can be reduced by better styling. The use of low profile power trains can help reduce frontal area. The resulting heavily-raked bonnets also provide good visibility with less glass and, hence, less mass. Frontal area can be further reduced by placing rear vision devices inside the car (by using TV cameras or special optics).

Figure 3.8: Spirit of Biel solar car

Unnecessary Losses

While manufacturers achieve improvements in aerodynamic design, vehicle users can undo some of this benefit through the way the vehicle is used. Roof racks add considerably to aerodynamic drag and are likely to be fitted for long journeys at highway speeds where their effects are most felt. Open windows break down the laminar flow of air around the vehicle and are one argument in favour of the use of interior airconditioning, particularly at speed. Trailers also create aerodynamic losses disproportional to their size.

3.7 Tyre/Road Interaction

Role of Tyres

The rolling resistance of motor vehicles depends to a large degree on the tyres. The tyres are required to provide maximum grip on the road surface, to sustain the longitudinal, transverse and vertical forces exerted on them, flush away standing water, operate with a minimum of noise and, at the same time, offer least resistance to motion.

Inevitably, there are energy losses at the tyres, primarily through hysteresis loss as each point on the tyre's surface deforms and regains its shape during each turn of the road wheel. The design of the tyre assumes correct inflation and wheel alignment. Incorrect pressure and misalignment of the wheels can cause excessive wear, an increase in resistance and, therefore, energy consumption. This is particularly important for heavy vehicles, for which the costs are more critical, and it is believed that there is room for improvement in the maintenance of the New Zealand road transport fleet in this respect.

Heavy Vehicles

Ramshaw and Williams (1981) provide experimental results on commercial vehicle tyres comparing radial and cross-ply construction. Replacement of cross-ply tyres with radials on an articulated vehicle was found to reduce fuel consumption by 2% on a test track and 6% under motorway driving conditions. Replacement of dual cross-ply tyres with super-singles gave a reduction of 4% on the test track and 10% on the motorway. The importance of inflation pressure was highlighted, as under-inflation increases resistance. Tyre temperature is also important as the rolling resistance decreases with increasing temperature. Smaller diameter tyres generally have greater rolling resistance than those of larger diameter.

In-use monitoring of tyre inflation pressure has been suggested in New Zealand and is believed to be technically feasible. Such a system would have advantages for the transport operator in warning of dangerously under-pressured tyres as well as saving costs in fuel and tyre wear.

Motor Cars

Rolling resistance, r_o — the ratio of tyre drag to the vertical load it supports — is not well understood. This nonrecoverable loss typically totals 0.007 to 0.01 for modern radial tyres, about half the 0.02 for typical 1970 vintage cross-ply tyres. In 1990, Goodyear produced a tyre with satisfactory handling characteristics and an r_o of 0.0048. This tyre was developed for GM's concept Impact electric car and was conventionally rated for 80 km/hr. Tyres for solar cars such as the Spirit of Biel have rolling resistance figures of 0.003 to 0.004, but they do not have high performance requirements in other areas (such as wet weather braking ability).

Future Developments

For a given set of environmental conditions, r_o depends on energy losses in the tyre and tread deformation. The key to better performance is arcane design subtleties and low hysteresis materials. Tyres and vehicles have to be designed to match one another in terms of acceleration, speed, mass and so on. Tyres must satisfy many functions, some of which are counter to reduced rolling resistance. The need for compromise becomes particularly evident with light vehicles lightly loaded. For example, loss of wet and dry condition braking could occur with too low an $r_{o.}$

Nonetheless, tyre manufacturers are seeking to reduce rolling resistance while maintaining handling qualities. For example, Michelin is in the process of launching its "green tyre" a new design that it is claimed will result in a fuel economy improvement of 5% over previous designs. It is believed that other tyre companies are also producing new products to match this marketing challenge. Furthermore, designers are looking at new tyre configurations, especially for heavy vehicles. Variable-camber double-tyre, variable pressure and unusual cross-section designs are being examined.

Road Surface Effects

Investigation carried out by Works Central Laboratories in New Zealand has indicated that modest improvements in fuel efficiency can be achieved through the use of thin asphaltic concrete overlays and finer grade chipseal than are usually used on the state highway system. Together with the reduced tyre wear, the total user benefits would exceed the extra paving costs borne by Transit New Zealand.

3.8 Reducing Accessory Loads

Introduction

Engine cooling fans, car interior heaters and airconditioners, lighting and other accessories can draw a significant amount of power from a car engine. The use of electric thermostatically-controlled radiator fans can reduce power losses by ensuring the fan is only operated when needed. Adopting technologies such as halogen globes has provided better headlighting for the same power demand. The use of ultraviolet headlighting is under development. This can take advantage of the luminescent qualities of many fabrics and other materials under ultraviolet light. For example, pedestrians can be seen further down the road with ultraviolet than with white-light beams.

In a conventional car, interior heating, demisting, etc. is largely supplied from engine waste heat. Electric vehicles do not have this waste energy source and, consequently, heating can reduce their effective range by 40% or more. Reducing accessory loads will be an important requirement for successful electric vehicles. Many cars have airconditioning and the proportion is likely to increase. Airconditioning adds to comfort, safety and, by enabling windows to remain closed, reduces aerodynamic drag. Manufacturers have, however, had little incentive to provide efficient airconditioners. Many testing procedures, including the Californian Corporate Average Fuel Standards, measure fuel economy without airconditioning operating. The main concern with car airconditioners in recent years has been the CFC/ozone depletion issue. CFC use in vehicles has now been phased out, but the replacements may still have some slight ozone depleting potential.

There is little information on the power drain of car airconditioners. Where they are fitted, they could use 10%

to 15% of the engine power output. Many vehicles have airconditioners that would be capable of cooling the average house. This is partly a reflection of their inefficiency, but also derives from the desire to have them quickly cool vehicles that have been standing in the sun. A twin-pronged approach to air conditioning is needed: reduce the load on the system and make the system more efficient.

Managing Solar Gain

The single largest climate control problem in most vehicles is reducing solar gain through window glazing. The trend in automobile design has been towards larger, more steeply sloped windows. This has improved aerodynamics and visibility, but has also increased the solar gain. On a hot day a car interior can reach 65˚C and surface temperature can exceed 90˚C. Thermal management using advanced window glazing and fans can address this problem. Photovoltaic-powered ventilation fans can substantially reduce the interior temperatures for cars parked in the sun without compromising vehicle security. Due to work on commercial building technologies, several promising glazing technologies are available or under development. Ideally, selective glazing will transmit most of the visible light while reflecting infrared and ultraviolet light.

Tinted glass tends to absorb and re-emit rather than reflect infrared. While this is helpful, it is not as effective as glass with selective reflective films. Silver-based films provide a possible solution. A degree of visible light reduction, which would further reduce solar gain, may be acceptable for the rear and rear side windows. While still in the development phase, electrochromic films offer great promise. Whatever technology is developed, it will be important to maintain pedestrian-to-driver and driver-to-driver eye contact for communication and, hence, safety. A problem arises with very dark and mirrored glazing surfaces in this regard.

Vehicle Insulation

Winter heat losses, likely to be a particular problem with electric vehicles, can be reduced by using body insulation, low-emissivity films and thin, double-glazed windows. The information in Table 3.3 shows the range of electric vehicles could be increased by nearly 30% through body insulation (Hopkins, 1994). Double-glazed windows are used on a few European sedans to reduce passenger compartment noise levels. Lightweight, CFC/HCFC-free, gas-filled insulating panels are under development.

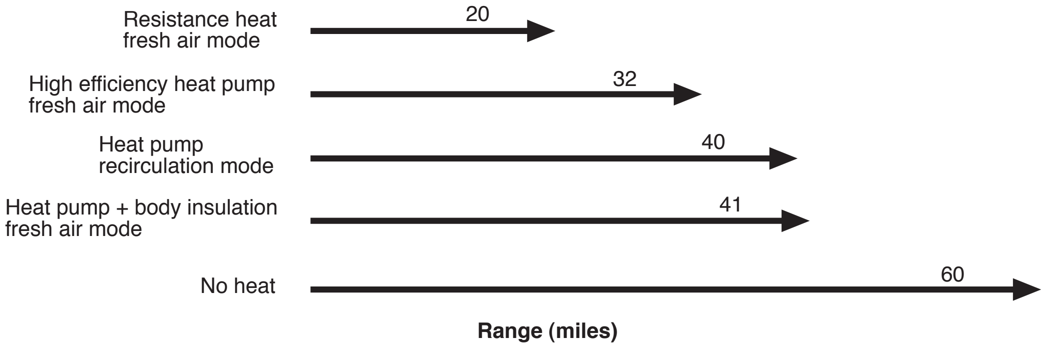


Table 3.3: EV range for different heating options (Hopkins, 1994)

While insulation may appear to add weight to a vehicle, it can form part of a foam sandwich construction that is inherently light and strong. Solar management and body insulation can provide a wide range of benefits including improved thermal comfort, reduced glare, quieter ride, reduced degradation of interior surfaces and improved fuel efficiency.

3.9 Waste Heat Recovery and Reuse

Approximately 75% of the energy in the fuel used by a car is lost as waste heat in the exhaust and cooling system. As mentioned above, some of this waste heat is used in cold weather for vehicle interior heating. There are two other potential and significant uses for this waste heat: engine pre-warming before startup and air conditioning. These uses are described below.

Cold Starting and Energy Loss

When a petrol or diesel engine is started from cold, it consumes more fuel over the first few kilometres than when fully warmed up. This excess consumption is mainly caused by:

- high viscosity and poor distribution of lubricants on startup;
- quenching of fuel on relatively cold combustion chamber surfaces and consequent incomplete combustion; and
- heat transfer to cold cylinders and pistons rather than into gas expansion and motive power.

Other factors include poor vaporisation of the fuel in the combustion chamber and the sometimes wasteful automatic and manual choke systems used to counter cold starting difficulty (though fuel injection and effective engine management systems have largely overcome this problem). Battery power is also lowest at low ambient temperature.

The size of the cold starting penalty and its duration depends on engine and drive train temperature. Figure 3.9 shows the excess fuel requirement per kilometre as a function of trip distance, based on United States studies (Stone, 1989, reported in Mendler, 1992). After travelling about 50 km, the vehicle is fully warmed up. For the same travel speed, a vehicle on a short trip of only 5 kilometres may consume 25% to 35% more fuel per kilometre than the average amount needed for a longer journey.

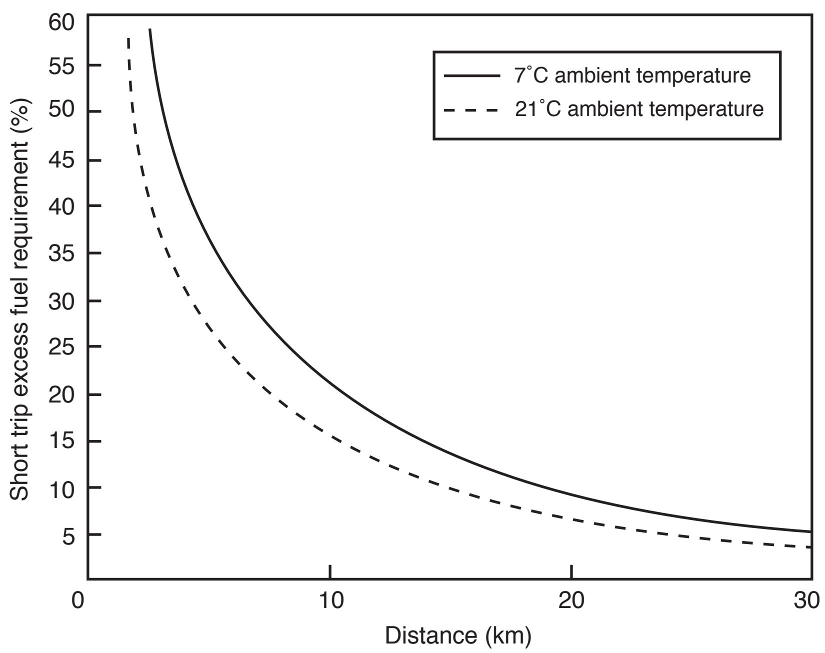


Figure 3.9: Excess fuel required for cold start trips in a Ford Pinto at 72 km/hr

Heat Storage Systems

In extreme climates, electrical engine warmers are necessary to allow the vehicle to start at all. Clearly, there is potential for energy savings if this cold starting penalty could be avoided or reduced in the conventional petrol engine.

One possibility is to store the heat developed during engine operation after the vehicle is shut down and to use this heat at a later time to pre-heat the engine prior to restarting. Industrial Research Ltd. (formerly DSIR) has been developing such a device, which it intends to publicise with a view to commercialisation (Waring, 1994). When the vehicle shuts down, water from the vehicle's cooling system is held in vacuum container, then recirculated when the vehicle is restarted.

Figure 3.10 shows the effect of the heat battery under different startup conditions. Fuel consumption is expressed as kilometres per litre. The best result, the top line, is for an engine that has been turned off and then restarted before the engine coolant temperatures fall below normal running levels. In this case, the heat battery has little effect. It is interesting to note that the vehicle requires 20 kilometres before the fuel consumption stabilises. This is probably due to oil viscosity, low cylinder head temperatures, etc.

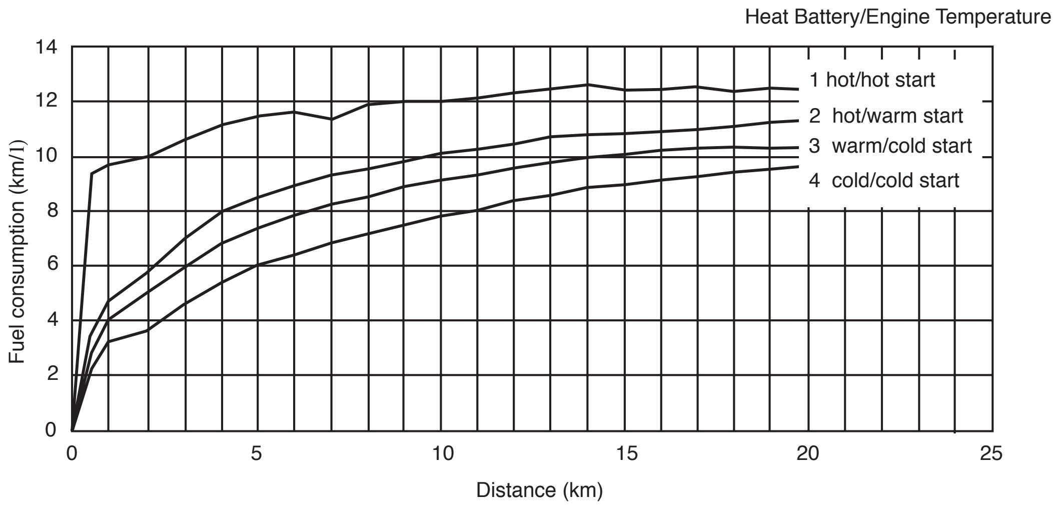


Figure 3.10: Heat battery performance

The bottom curve in Figure 3.10 is for a cold engine start with no preheating. The curve second from the bottom shows what happens after leaving the vehicle outside all night. The engine is cold, but the heat battery is warm and can provide some preheat on startup. The second curve from the top shows the effect of leaving the vehicle for a few hours. The engine is warm while the heat battery is still quite hot.

The data in Figure 3.10 shows that the effect of the preheating device is equivalent to an approximately 20% improvement in fuel economy over a 20 km distance after an overnight stop (curve 3 versus curve 4). An even greater improvement in economy occurs after a stop of a several hours where the engine is already cold, but the insulated water is warmer than after an overnight break (not shown on the figure, but approximates to curve 2 versus curve 4).

A number of overseas manufacturers are also developing heat batteries. Figure 3.11 shows a typical layout. The system being developed by Volkswagen has a 10 kg storage cylinder and is capable of delivering 60 kW of heat for approximately 8 seconds. In addition to storing heat in the form of insulated hot water, it is possible to store it in saltwater hydration systems. This technology is discussed below.

As a large proportion of vehicle travel is for trips of relatively short distance, application of heat batteries could have quite a significant impact on fuel use. Furthermore, they can lead to reduced emission of pollutants, less engine wear and lubricant degradation and better response from the interior heater.

Airconditioning from Waste Heat

Absorption heat pumps use a working fluid that consists of a mixture of a volatile component, the refrigerant, and a relatively non-volatile component, the absorbent. The thermodynamics of absorption heat pumps are described in Part 8 of Volume II, "General Industrial Technologies". One system particularly suitable for automobile use has been developed using a mixture of a salt, sodium sulphide and water (de Beijer, 1993). Heat can be stored by driving off some of the water vapour from the saltwater mixture in a low pressure system and keeping the two components separate. No insulation is needed as the sensible heat only amounts to about 5% of the energy storage, the balance being chemical energy. The relevant chemical reaction is:

$$Na_2S.nH_2O + \text{heat} \rightarrow Na_2S + nH_2O$$

The heat can be recovered later by applying a small amount of low grade heat (this could be from ambient sources, or a hot car interior) to the water vapour and allowing it to rehydrate the salt. In one case, the resulting heat could be used (e.g. in an engine preheater). In another case, the heat could be dumped, but the process used to provide cold air by drawing heat from the car interior to evaporate the water so it can recombine with the salt. By using a two-unit or batch system alternately, continuous airconditioning can be provided. The capacity of the system is 1 kWh of heat storage and 0.7 kWh of cooling per kg of Na_2S.

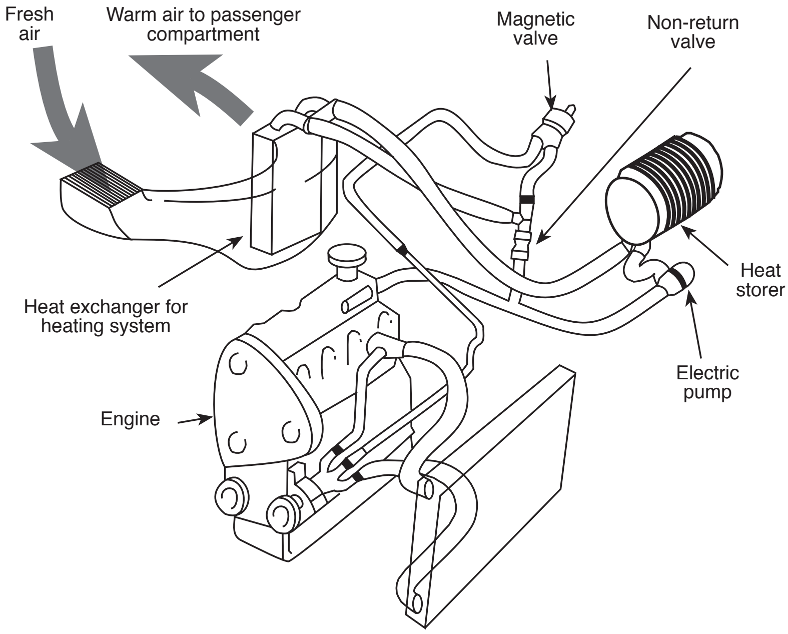


Figure 3.11: Typical heat battery system (Automotive Engineering, 1991)

This heat storage/heat pump system is attractive for electric hybrid vehicles. It can be used to provide climate control when the combustion engine component of a hybrid is not running.

3.10 Future Outlook for Car Fuel Economy

Potential for Improvement

The theoretical reduction in light vehicle fuel consumption and what may be achieved in practice could differ greatly. It is clear, however, that there are still quite large gains to be made in passenger car fuel efficiency and the rate at which these gains are achieved will, to a large extent, be driven by economics and by the policies adopted by influential governments with large domestic auto industries, such as the USA and Japan.

In Australia, Watson (1990) envisages that new car fuel economy on a "best likely" scenario could improve from 9 litres/100km in 1990 to between 4 and 5 litres/100km by the year 2010. Introducing legislation to restrict sales to smaller models of car could bring this down to below 4 litres/100km. Under such a scenario, total fuel use by cars in Australia is likely to peak in the mid-1990s and then decline as the effects of fuel efficient technology overcome the slackening upward growth in car ownership.

The technical feasibility of reducing fuel economy below 4 litres/100km has been clearly demonstrated in the "concept cars" produced by leading manufacturers. For example, Waters (1992) describes the Volvo LCP 2000, a two-seater powered by a three-cylinder turbo-charged diesel, which has achieved 3.6 litres/100km in a mix of urban, rural and motorway driving.

Lovins (1993) considers that 150 mpg (around 2 litres/100 km) is ultimately feasible. Figure 3.12 summarises the types and magnitudes of improvements that are considered, by a more conservative commentator (Mendler, 1992), to be feasible in the medium term. Reduced weight, improvements in transmissions and petrol and diesel engine refinements appear to offer the greatest potential for improvement.

There are signs that the major manufacturers are earnestly seeking to realise the available potential. In the United States, General Motors, Ford and Chrysler have entered a cooperative research and development agreement with the federal government aimed at producing a "new generation of vehicles" (General Motors, 1994). Managed jointly by automobile industry and federal inter-agency teams, this partnership focuses resources of the US National Laboratories, universities and domestic manufacturers and suppliers on achieving the technological breakthroughs needed to make additional fuel economy gains at reasonable cost, while meeting other customer requirements.

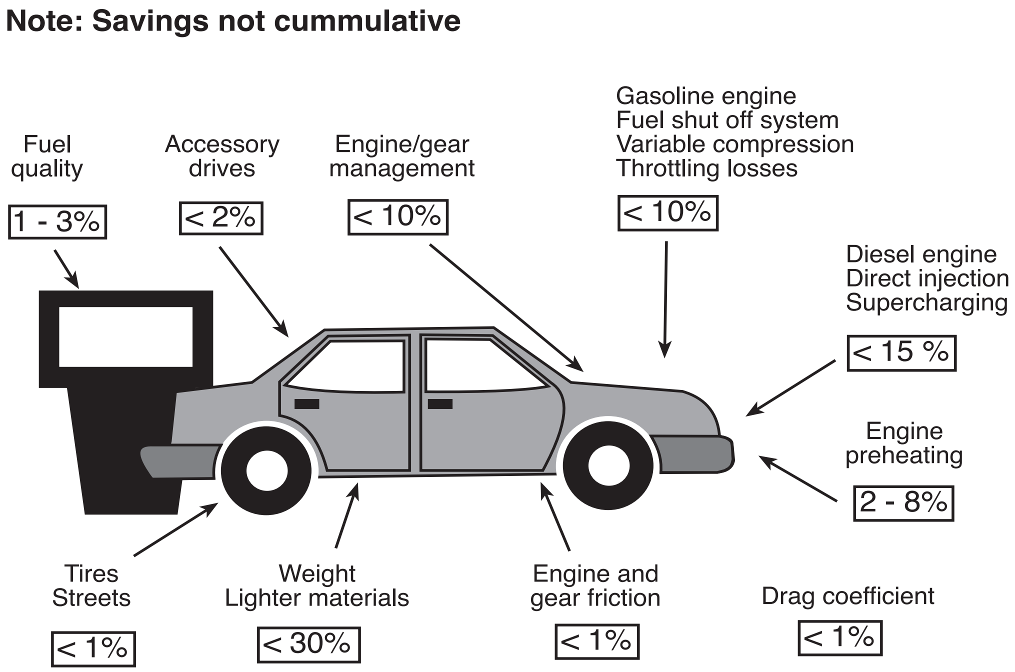


Figure 3.12: Potential for medium term efficiency improvements

Forecasts

While new technology will reduce the lower bound of fuel economy in passenger cars, these new innovations will take time to penetrate the market and not all the buying public will purchase the smallest and most fuel efficient vehicles. There is a significant difference between what it thought to be technically feasible, and even cost effective, by some analysts and what is forecast to occur given consumer trends, public policies, etc.

Light vehicle fuel consumption will be significantly affected by the severity of emission control regulations demanded in the main consumer markets, namely Europe and the USA. Martin and Shock (1989) analysed the impacts of impending legislative changes to emission controls for petrol and diesel vehicles and concluded that a 10% to 15% improvement was likely for petrol cars between 1986 and 2010, dropping from 9.6 to 8.4 litres/100km. For diesel engine cars, emission control regulations were expected to offset any further improvement, diesel cars achieving 5.8 litres/100km in 2010 compared to 5.9 litres/100km in 1986.

The IEA/OECD (1992) have suggested national estimates for new car fuel economy that show base values for 1990 of between 7.2 and 8.7 litres/100km over a range of countries, falling by the year 2010 to a range of 5.5 to 7.6 litres/100km.

New Zealand Situation

The various figures above can be compared with the estimated mean fuel consumption of 9.6 litres/100 km for the car fleet in New Zealand as a whole in 1992, measured indirectly from fuel delivery statistics and estimates of annual vehicle-kilometres of travel (Beca Carter, 1994). This compares with previous estimates of around 10.5 litres/km in 1986 (Beca Carter, 1986) and approximately 12 litres/100 km in 1975 (Beca Carter, 1977).

New car fuel consumption is currently estimated to average 7.3 litres/100km (Bone et al., 1993) although this relies on various assumptions regarding the driving cycle and rate of deterioration in vehicle fuel economy with age that are hard to confirm. This relatively low figure is encouraging but needs to be treated with some caution. Only a few years earlier, in 1990, New Zealand was reported as having a new car fuel consumption of 8.7 litres/km, which was higher than the figure for the United States at that time (International Energy Agency, 1991). In the absence of any requirement for importers and local vehicle assemblers to disclose consumption figures, New Zealand estimates are based on such methods as relating engine size to consumption for a driving cycle assumed to be appropriate to this country.

Several important points arise from this chapter. Firstly, there are a wide variety of technologies available or being developed that could make motor cars more efficient. This is good news for a nation that relies heavily on the private car for mobility. Secondly, the technologies cover a wide range of fields and there may be opportunities for New Zealand business, universities and research institutions to play a role in their development.

The final point is that New Zealand need not be a passive player in the matter of vehicle efficiency. There are already large differences in the fuel economy of production cars. New Zealand could adopt public policy measures to encourage consumers to chose the more efficient vehicles from those that otherwise suit their needs. Furthermore, there are retrofit and other specification options that could be mandated through regulations and standards. The public policy options for facilitating purchase of efficient vehicles are outlined in Chapter 8 “Public Policy Options”.

Chapter 4
Alternative Fuels and Engine Systems

This chapter provides an overview of developments in the areas of alternative fuels and engine systems. The first three sections are devoted to alternative fuels, while the fourth covers new engine systems. As engines and fuels cannot be separated, there will be some overlap between the material in the various sections.

4.1 Alternative Fuels and Energy Efficiency

In New Zealand, the bulk of light vehicles operate on either premium (leaded 96 octane) or unleaded (91 octane) petrol (unleaded 96 octane petrol is being introduced in 1996 to replace leaded 96 octane petrol). In terms of liquid fuels, New Zealand is around 50% self-sufficient. Condensates are extracted from the Maui field and some of the natural gas from the field (and from the Kapuni field) is converted into synthetic petrol at the Motonui Synfuels plant in Taranaki. All of the alternatives to gasoline currently in general use — diesel, LPG and CNG — are more energy efficient, produce less greenhouse gas emissions and are cheaper than gasoline. For a variety of reasons, some of which are discussed below, they are not used as much as they could be.

There are a range of other alternative fuels under development overseas. The motivation for developing these fuels is varied. After the second oil shock, some nations were concerned to increase liquid fuel self-sufficiency. They may have had access to abundant coal, natural gas or biomass resources that could be converted to liquid transport fuels. More recently, the desire to mitigate air pollution problems has become a significant motivator, especially in the United States and Europe. The move towards sustainable energy systems and concern to reduce greenhouse gas emissions has sparked a keen interest in biomass-sourced fuels, in particular.

Energy Conversion Issues

Compared with producing petrol or diesel from crude oil, producing other liquid fuels from oil or natural gas is not energy efficient. Figure 4.1 also shows the conversion efficiencies for a range of fuels that may be suitable for transport use (Huss, 1992). Around 10% of the energy content of crude oil is lost in producing petrol. The efficiency of converting natural gas to synthetic petrol at the Motonui plant is a bit over 50%. Taking the energy required to compress natural gas to CNG as a conversion loss leads to a CNG efficiency of 98%. Figure 4.1 shows an entry for electricity from nuclear power. Producing electricity from natural gas fired via a combined-cycle power station is typically around 40% efficient, once transmission losses are accounted for.

During the 1980s, the New Zealand Liquid Fuels Trust Board (LFTB) commissioned a large number of studies into the South Island lignite resource with an eye to its possible use for conversion to transport fuels such as methanol (Reports LF 1022 to LF 1095 inclusive, see Isaacs, 1993). Figure 4.2 shows the energy flows and carbon dioxide emissions from producing methanol from brown coal (lignite). The tailpipe emissions are only a fraction of the total and this needs to be considered in any public policies on alternative fuels. Methanol can be a reasonably clean-burning fuel, which is why it is mooted as an alternative to petrol in places such as California, where it is hoped that production plants could be located away from pollution-prone areas. Furthermore, methanol can be produced from natural gas and California has good access to this resource.

Biomass Systems

Figure 4.3 shows the conversion pathways that are under development for conversion of biomass into energy or liquid fuels (Sims, 1993). The biomass input can be wastes, purpose-grown crops such as lucerne, grains, sugarcane, etc., or even meat processing wastes. Of particular relevance to New Zealand is the conversion of wood (ligno-cellulose) to ethanol. Methanol can also be produced via the fermentation path. Not shown on the figure is the anaerobic digestion of biomass to produce methane gas, which can substitute for CNG. Direct gasification of wood is also not shown. This approach is not suitable for modern transport as the gas has to be used where it is produced, and larger amounts of wood would need to be carried by the vehicle. Of course, in the past some steam trains were wood fired.

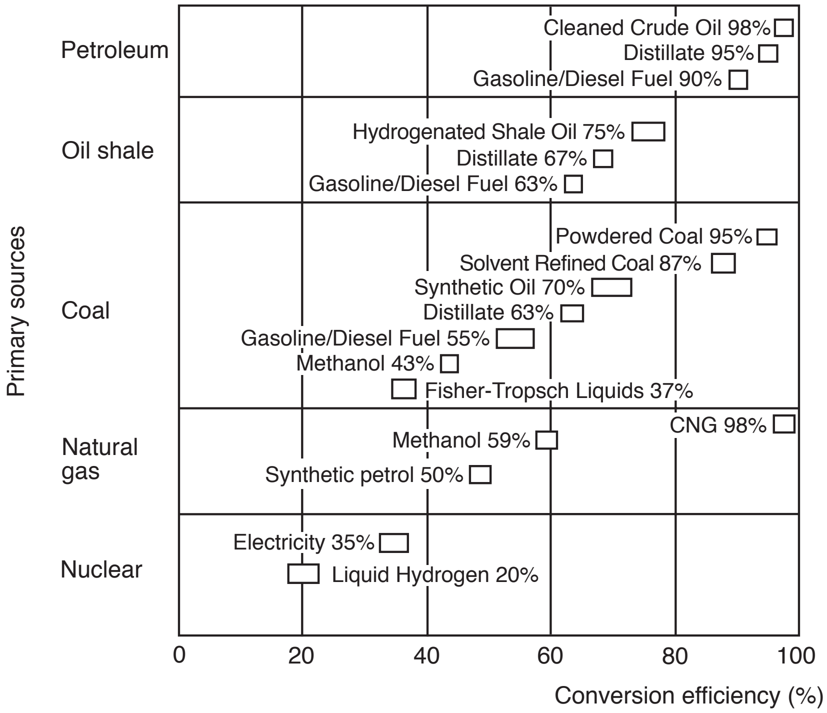


Figure 4.1: Fuel conversion efficiencies (Huss, 1992)

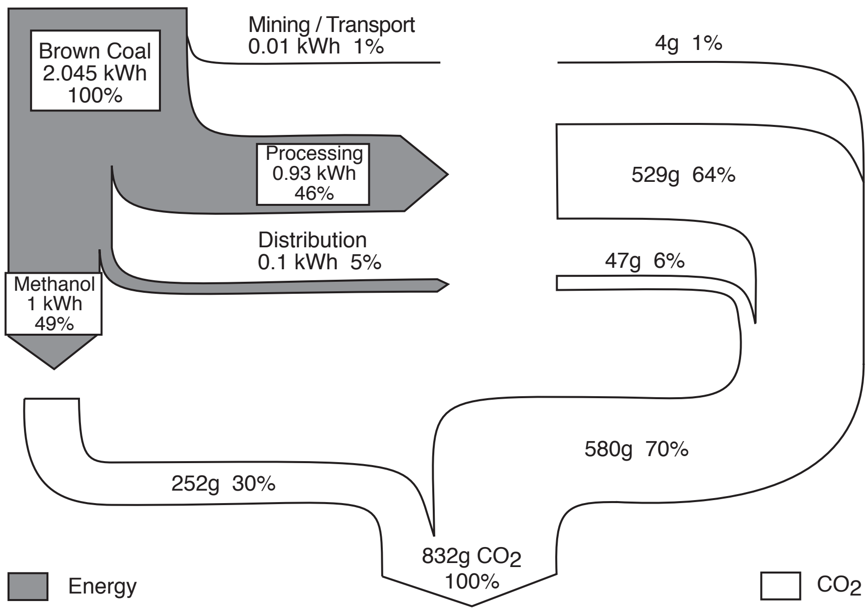


Figure 4.2: Methanol production from brown coal — energies and emissions (Huss, 1992)

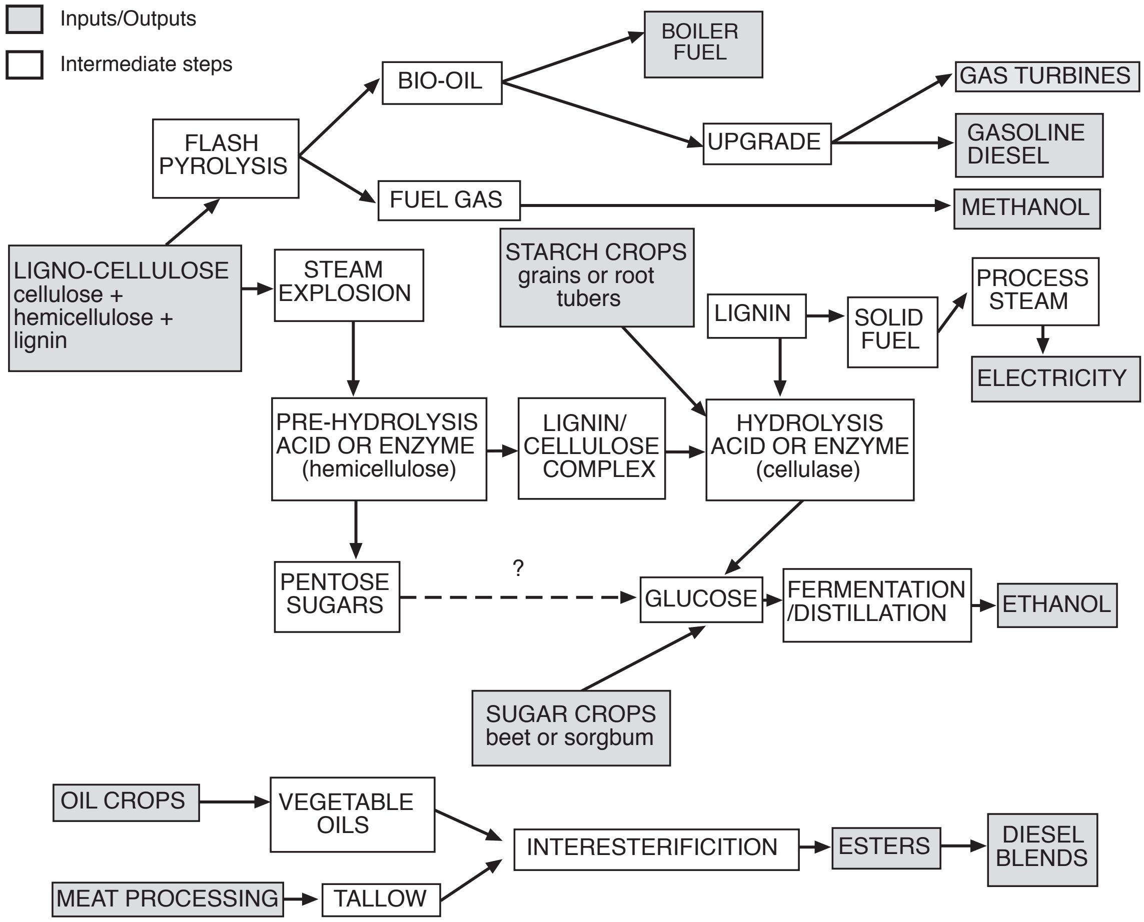


Figure 4.3: Energy conversion routes for biomass (Sims, 1993)

The production and conversion of biomass to transport fuels requires energy inputs, usually fossil fuels, but nonetheless there is a net energy gain and a number of other important advantages. One of these is that it may be possible to develop fully sustainable renewable energy systems around biomass crops. Figure 4.4 shows the primary energy inputs and outputs for European production of rapeseed oil, an alternative to diesel. After allowing for agricultural and processing energy inputs (3 units of energy), and the rapeseed oil output (4 units), there is a net energy gain (1 unit). The energy input:output ratio for rapeseed oil is 0.75, a similar figure to that for ethanol from corn.

All the carbon dioxide produced when the rapeseed oil is burned can be considered to be recaptured by the growing crop. If only the emissions associated with the energy inputs are considered, then using rapeseed oil could effectively reduce carbon dioxide emissions from a diesel vehicle by up to 25%. Figure 4.4 also shows that rapeseed oil production produces potential energy byproducts, such as straw. These could be used to offset some of the fossil fuel inputs so that a near-sustainable energy system is developed (issues of soil fertility loss, tillage methods and wind erosion, etc. would, however, need to be addressed). The aim with biomass conversion processes is to achieve a low energy input:output ratio and preferably one where little or no fossil fuel input is required.

Another measure of the environmental implications of an energy system is its greenhouse gas emissions. Table 4.1 shows the emissions from a variety of alternative fuels relative to those from petrol production and use (Deluchi, 1991). Note that nuclear energy is not emission-free as significant amounts of fossil fuel have to be used in the refinement of uranium ore. Of particular interest to New Zealand is the entry for ethanol from cellulose.

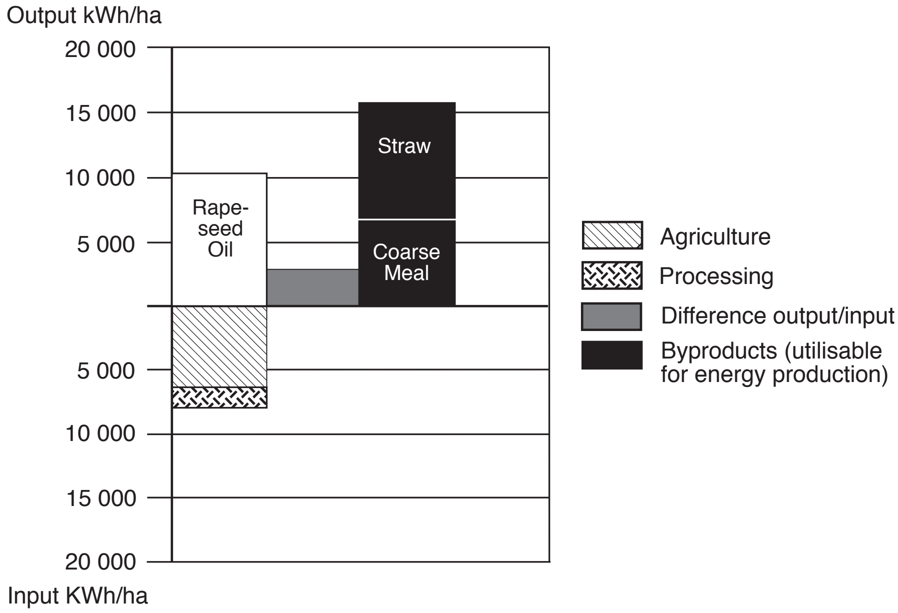


Figure 4.4: Energy balance for rapeseed oil production (Huss, 1992)

Fuel cells (solar-hydrogen)	-90 to -85
Ethanol from cellulose	-75 to -40
Hydrogen (nuclear electricity)	-70 to -10
LPG	-30 to -10
Electric vehicle (natural gas combined cycle)	-25 to -10
Natural gas vehicle	-20 to 0
Electric vehicle (current USA energy mix)	-20 to 0
Methanol from natural gas	-10 to +8
Ethanol from corn	-10 to +35
Electric vehicle (coal)	+25 to +50
Methanol from coal	+30 to +70

Table 4.1: Greenhouse gas emissions relative to petrol, total fuel cycle, advanced technology vehicles, CO_2 equivalent (Deluchi, 1991)

Tree crops have a favourable energy balance compared with grain crops (rapeseed or corn). The amount of energy input needed to run a timber-based system may range from 5% (long rotation forest) to 25% (short rotation fuelwood lots) of the calorific value of the timber produced (Sims, 1993, Collins, 1992). Research is underway to find more efficient processes for converting cellulose into liquid or gas transport fuels. If successful, then forestry may play a major role in New Zealand's sustainable energy future.

The development of biomass energy systems evoke a wide range of issues, particularly environmental and landuse issues. To make an effective impact on fuel supplies, vast areas of land would need to be allocated to crop production. While establishing a forest, for example, may confer soil conservation and catchment protection benefits, both trees and other energy crops can be in competition with other landuses. Creating an effective energy cropping infrastructure would require a large number of landowners to make long-term commitments to processors and, except for the dairy industry, this is not a common occurrence in New Zealand agriculture. Provision would need to be made for biomass stockpiling and other measures to counter climatic variations.

Other Renewable Systems

Electricity for vehicles can be produced from a range of renewable resources. In addition to biomass, these include wind or hydro resources or solar energy via photovoltaics. Solar panels could be mounted on the roof of an electric or electric-hybrid vehicle. Electricity can be used to produce hydrogen via hydrolysis of water. Whole energy production, storage and distribution systems have been proposed around hydrogen. Liquid hydrogen has been suggested as an aircraft fuel and it may also be suitable for shipping. Compressed hydrogen could be used in cars, but its low energy density will present a challenge. Figure 4.5 shows that the energy density of compressed hydrogen is about one-third that of CNG (Huss, 1992). By storing hydrogen in special hydride vessels, the volume density can be improved (it can be tripled, but at the expense of extra container dead weight). Low energy density is clearly a problem for electricity storage as well.

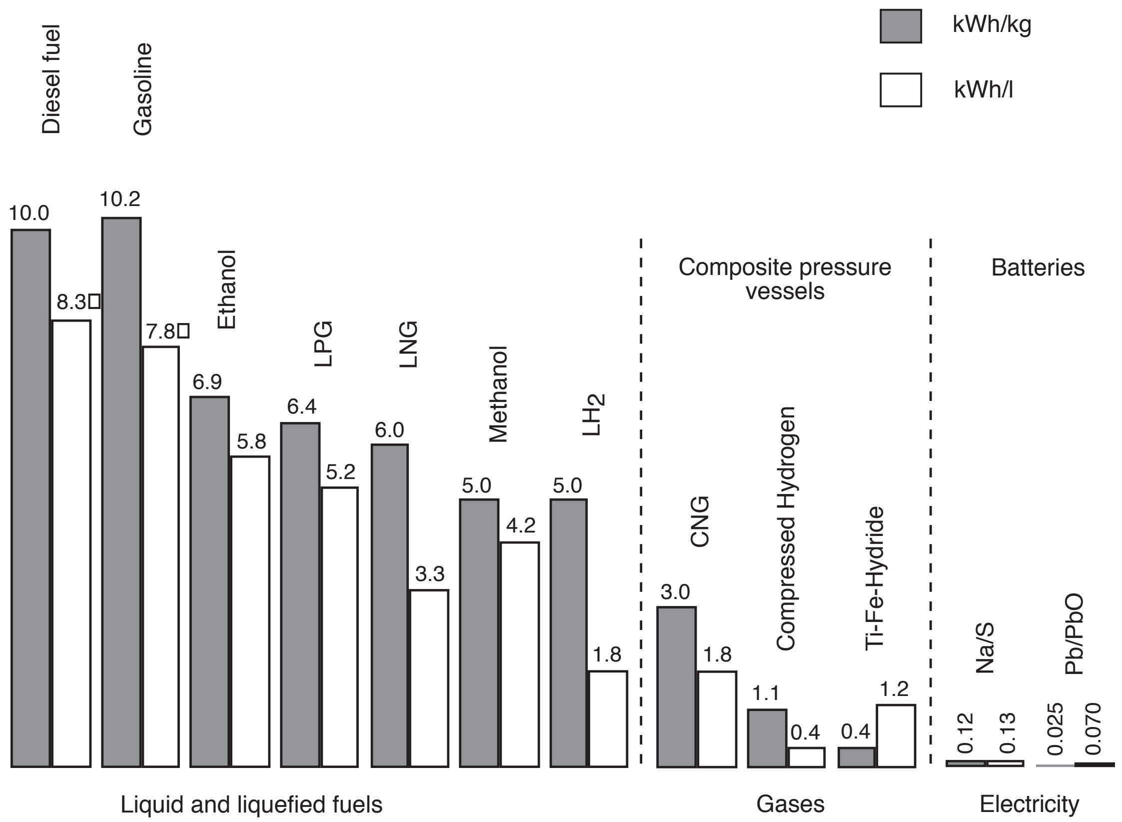


Figure 4.5: Energy densities of fuel storage systems (Huss, 1992)

Other Considerations

A critical point is that fuels and engine systems cannot be considered in isolation. Engines need to be designed and optimised for particular fuels. Furthermore, an engine is not much use if the infrastructure is not available to supply the fuel. This " chicken and the egg" problem can frustrate the introduction of alternative fuels. Very efficient engine system components, such as fuel cells, are being developed, but face a range of safety, maintenance support structure and other issues. Figure 4.6 summarises the main considerations in the assessment of engine systems and fuels.

Sections 4.2 and 4.3 provide more information on common alternative fuels and potential future alternative fuels. Section 4.2 covers fuels already available and used in New Zealand. Section 4.3 covers fuels little used or not yet available in New Zealand (they may be available overseas). The fuels discussed are:

- common alternative fuels

  — diesel

— LPG and CNG

- future alternative fuels

— alcohol fuel

— hydrogen

— electricity

Section 4.4 discusses how both conventional and alternative transport fuels could be used in new engines or new engine systems, such as electric-hybrid drives.

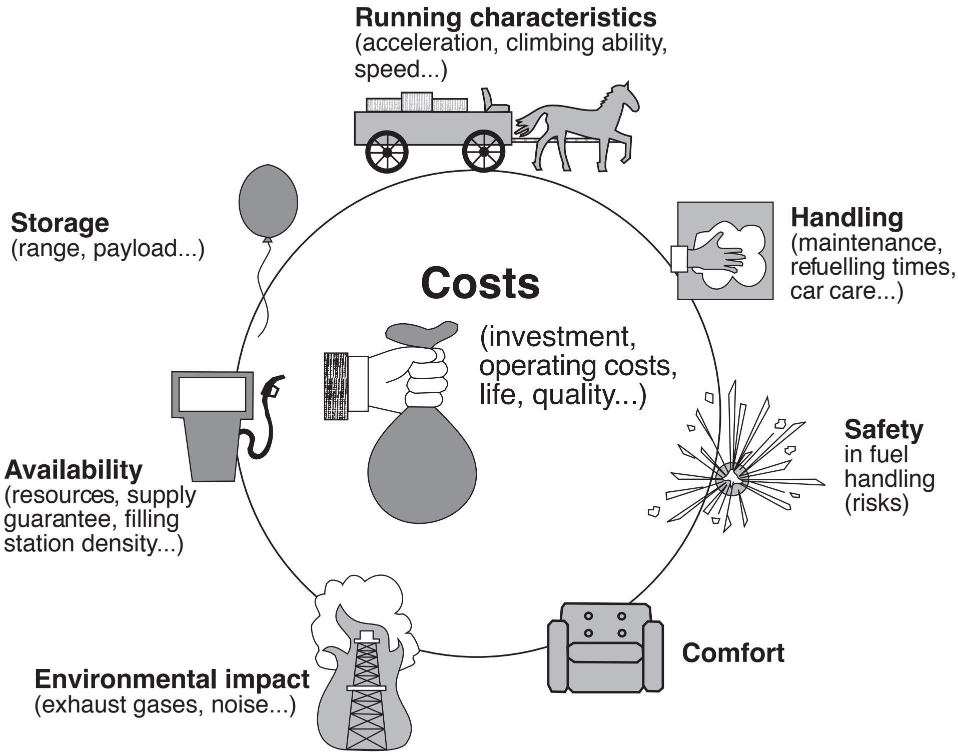


Figure 4.6: Criteria for the assessment of propulsion systems and fuels

4.2 Common Alternative Fuels

Diesel Substitution for Petrol

Substituting diesel for petrol in cars and light commercial vehicles is a step that could be taken fairly quickly. Already, diesels command a significant share of the car market in Europe, and in New Zealand over 6% of imported used cars are diesel-powered (compared with 1.3% in the car fleet as a whole). The use of these ex-overseas vehicles in the taxi fleet is particularly noticeable.

The diesel cycle is intrinsically more thermally efficient than the Otto Cycle and a diesel engine may be 20% to 30% more efficient in practice than its typical petrol equivalent. Furthermore, technologies are being developed to make diesel engines even more efficient (Archer, 1992). Why vehicle importers and assemblers have not taken the initiative to market diesel-engine cars more aggressively in New Zealand is a mystery. Certainly, the image of diesel has suffered in the past — a noisier engine, the need for a confusing separate pre-start and tendency for smoke pollution — but these deficiencies have now been largely overcome. Even the remaining problem for the diesel engine in some urban areas, its relatively high NO_x emissions, which would put it outside the emission control limits prescribed for future use in Europe and the USA, is expected to be solved by new catalytic converters.

Table 4.2 shows the most efficient production cars on the UK market in 1990 (Department of Transport, 1990). Seven out of the eight cars have diesel engines. The single petrol-engined entry, the Citreon AX10, is particularly efficient compared with other petrol-engined vehicles. Nonetheless, its diesel equivalent, the AX14D, has a 9% lower fuel consumption.

Manufacturer	Model	Fuel	Composite fuel consumption litres/100km
Daihatsu	Charade	Diesel	4.35
Citroën	AX14D	Diesel	4.41
Peugeot	205D	Diesel	4.63
Citroën	AX10	Petrol	4.71
Rover	Montego	Diesel	4.71
Renault	5TD	Diesel	4.79
Ford	Fiesta 1.8D	Diesel	4.87
Vauxhall	Nova 1.5D	Diesel	4.87

Table 4.2: Fuel efficient production cars on the UK market

Notwithstanding improvements in diesel engines, there is still concern in Europe about the toxic effects of diesel emissions, both the NO_x and the carcinogenic properties of residual unburnt and volatile hydrocarbons such as benzene. Particulate emissions are also a concern. Development in several areas is tackling these issues:

- Improving fuel combustion — alteration and modification of the fuel injection pressure, fuel delivery schedule and timing, injector and combustion chamber design, induction air swirl etc. Research and development is aided by new modelling and photographic techniques (Winklhofer, 1992).

- Exhaust scrubbing and treatment — for example, centrifugal removal of particulate material and its periodic automatic incineration using electric resistance heating has been trialled on buses in Europe.

There would appear to be few constraints — environmental, comfort, performance — acting against more widespread introduction of diesel-powered vehicles in New Zealand (apart from a slightly higher initial cost, which is countered by cheaper fuel). However, the requirement for all diesel-fuelled vehicles to pay road user charges may be a constraint for some car owners. While it appears likely that many cars in fact fail to do so, through ignorance or avoidance, the process of pre-purchasing a licence based on distance travelled is a cumbersome and foreign requirement for the general car user.

LPG and CNG

New Zealand was one of the first countries to promote a programme for substitution of the two gas fuel alternatives to petrol — liquefied petroleum gas (LPG) and compressed natural gas (CNG). As a result, New Zealand experience was often drawn upon or reported overseas (CADDET, 1991). The primary reason for the introduction of CNG and LPG in the late 1970s was for economic savings and import substitution. Relatively little attention has been given to the potential energy savings with these fuels, particularly CNG, even though these savings are significant.

Tests carried out by the Gas Association over the past six years on a range of new and older model vehicles have indicated that CNG vehicles are, on average, approximately 8% more fuel efficient under normal driving conditions than similar petrol-powered vehicles.

Few scientific tests have been carried out on LPG vehicles, but the indications are that LPG is around 5% more fuel efficient than petrol. When the full fuel production cycle is considered, the advantages of LPG and CNG over petrol increase further. In terms of carbon dioxide emissions, New Zealand CNG use is considered to create around 20% less emissions and LPG around 14% less emissions than petrol (Collins, 1993).

CNG has been trialled extensively in heavy commercial vehicles, both trucks and buses, but changes in the diesel taxation structure in the late 1980s has limited its regular use to a few bus fleets. As a result, little definitive data is available on the relative fuel efficiencies of diesel and CNG. From the limited results available, it would appear that CNG is between 5% and 15% less efficient than diesel when used in converted diesel engines. However, this has been found to be highly dependent on the standard of the conversion from diesel to CNG and the loading on the vehicle. Use of CNG or LPG in purpose-designed high compression engines is normally more fuel-efficient than in dual fuel systems, which was the normal form of conversion in the introductory years of these fuels.

Somewhat perversely, many overseas countries are taking an interest in these fuels as the use of CNG is declining and LPG use is levelling off in New Zealand, although the reasons are often more to do with reducing urban air pollution than for fuel efficiency or substitution purposes. The result, though, is further development on engine systems for these fuels. CNG vehicles offer the most scope for improvement and Table 4.3 shows the current and expected future performance of CNG compared with petrol and diesel (IANGV, 1994).

Vehicle/fuel	Relative vehicle efficiency	Relative CO_2
Light Duty Vehicles		
Petrol	1.0	1.00
CNG — present	1.0	0.81
— future	1.1 — 1.3	0.62 — 0.74
Heavy duty vehicles		
Diesel	1.3	0.79
CNG — present	1.2	0.67
— future	1.3	0.620

Table 4.3: Vehicle CO_2 emissions from CNG and conventional fuels (IANGV, 1994)

The future outlook for CNG use in New Zealand is uncertain. The refuelling infrastructure is still relatively intact. However, the number of public refuelling stations has fallen from around 360 to around 275, and as equipment in these stations comes up for replacement, oil companies could decide that continuation with CNG is no longer financially justifiable in some cases. In the case of LPG, conversions have been available at a virtually zero installation cost (provided the vehicle is dedicated to LPG use) under the LPG promotions scheme. However, this is due to close by the end of 1995, and LPG conversions may then become less popular. The economics of these gas fuels is not as favourable as it once was and can often only be justified in economic terms for relatively high annual utilisation vehicles, such as taxis. It would appear that the environmental advantages of these fuels are undervalued at present. If this was corrected through the price mechanism, then a resurgence in use of LPG and, particularly, CNG can be envisaged.

4.3 Future Alternative Fuels

Alcohol and Biomass Fuels

Alcohol fuels, primarily methanol and ethanol, are both excellent fuels for the Otto Cycle engine and have long been used in motor racing. Methanol can be manufactured from fossil fuels, such as natural gas or coal. Methanol production is the first step in the manufacture of synthetic petrol at the Motonui plant in Taranaki. This New Zealand example was the first commercial-sized implementation of the Mobil process for converting natural gas to methanol. Methanol and, more usually, ethanol, can also be derived from biomass sources, although fossil fuel prices will have to rise substantially (or biomass costs will have to fall) before biomass sources become an economic proposition.

Both methanol and ethanol are desirable for their high octane number but have certain disadvantages, such as miscibility with water, a tendency to separate from petrol if water is present and a lower energy density, which requires a larger fuel tank or limits vehicle range. Methanol, in particular, will attack some engine and other vehicle components such as fuel filters, carburettor components and certain paints, where these are not designed specifically with this fuel in mind. Exhaust emissions in alcohol-fuelled engines are significantly lower than for petrol, although there is a need to guard against aldehyde emissions under cold running conditions.

An extensive programme of research was carried out in the 1970s and early 1980s by the NZERDC into biomass sources and the LFTB into the application of methanol and ethanol as vehicle fuels, either as extenders in petrol/alcohol and diesel/alcohol blends from 10% to 20% or as the primary fuels (80% to 100% alcohol). Concurrently, ethanol was in extensive use overseas, notably in Brazil using sugarcane biomass feedstock and in the USA, while methanol was in use as an extender in various developing countries (Papua New Guinea, Zimbabwe, Malawi).

Sugar beets were examined as the most likely biomass source for ethanol production in New Zealand at the time, although there was a review of the hydrolysis and fermentation of wood. The primary focus of the New Zealand research effort was, however, on methanol blends as this was the fuel most likely to be readily available in this country (from natural gas). A considerable amount of work was done in testing the effects on performance and component deterioration of vehicles designed for use with conventional gasoline engines. The LFTB reported that its programme of vehicle trials and demonstrations was the most extensive and varied of any conducted in the world at that time.

Overall, the research programme concluded that a 3% to 5% methanol blend, together with 2% tertiary butyl alcohol to counter the water miscibility problem, would yield a positive net national economic benefit if distributed regionally or nationally in the existing vehicle fleet. The reduction in calorific value through the inclusion of the alcohol fuel would be offset by the increased blending octane number achieved.

Research in New Zealand by the NZERDC and the LFTB has looked as biogas production from wastes and the manufacture of tallow esters from animal residues from freezing works. The former fuel can substitute for CNG while the latter can be used as a diesel extender or substitute for diesel. During the 1980s, the Christchurch Drainage Board supplied biogas derived from sewage for a variety of vehicles, though this gas is now used for other purposes, including electricity generation (CADDET, 1991).

Electricity

Electric vehicles (EVs) have been in commercial operation for many years and can be generally subdivided into the following categories of electrical power supply:

- through a system of electrical reticulation — electrified rail or overhead;
- on-board battery storage; and
- on-board production of electricity, e.g. fuel cell technology and diesel-electric systems.

On-board production of electricity is treated as an electric-hybrid engine system and is discussed in Section 4.4. Many commentators consider that the future for EVs is as hybrid engine configurations (Lovins, 1993; Sperling, 1995).

The use of reticulated power has historically been the most common form of electric propulsion and includes

- street trams, which were in common use in New Zealand cities earlier in the century;
- trolleybuses, which have been phased out in all cities with the exception of Wellington; and
- rail systems running on a separated right of way.

The only urban electric train system in New Zealand is the Wellington multiple units. Part of the mainline rail system is also electrified (Palmerston North to Hamilton and the Otira Tunnel). Diesel-electric trains can either be operated on reticulated electricity or run as electric-hybrid units.

Reticulated systems have the advantage of not having to carry the deadload of electric batteries but have the disadvantage of being confined to the reticulated route and, hence, their use has been restricted to public transport fixed-route operation.

Battery electric vehicles have been in use for many years but are restricted to niche applications such as milk delivery trucks, fork lifts, golf buggies, invalid carriages and similar applications where conformity with fast moving traffic and range are not critical. There have been few on-road vehicles introduced to service in New Zealand so far. This could change in the future as electric cars are now commercially available in New Zealand. ECNZ has converted three Diahatsu Miras to electric propulsion and further conversions can be made on request to Diahatsu. These EVs have a range of 50 to 60 km and a maximum speed of 100 km/h. They are promoted as suitable for commuting, shopping, and for such commercial uses as city parking meter patrol.

The feature of the battery-electric vehicle which has limited its widespread use, is the low energy density of conventional battery systems — the quantity of energy stored per unit weight of battery. Also of importance is the power density of the battery, which governs the rate of acceleration that can be achieved. While power density does not provide a particular constraint, high power demand limits the range that can be achieved in conventional battery systems. Of course, safety, cost, reliability and ease of servicing are also important concerns if EVs are to have wide application.

Photoelectric cells can be used to provide electrical energy, but the size of solar array required to supply normal vehicle power demands would be very large. Solar power has been used in ultra-light experimental or solar racing vehicles. Solar panels could be used to augment other electric energy sources and to run some accessories. Cars parked outside for long periods between commuting journeys could find that solar panels are able to make a meaningful contribution to battery recharge.

Since electricity is cheaper than petrol or diesel, electric vehicles can be economical to run. Using off-peak power, the Diahatsu Mira can be recharged for approximately one dollar. Another important advantage of the electric vehicle is its low noise and zero tailpipe emissions, which makes it particularly attractive for those urban environments where pollution is severe. Indeed, the pressures to introduce electric vehicles in large numbers for urban transport over recent years stem mainly from concerns over environmental quality rather than for energy efficiency.

While electric vehicles produce no tailpipe emissions, they may not always be more energy efficient than competing vehicle types. The electric motor is a highly efficient converter of stored energy to useful vehicle motion, much more so than the internal combustion engine, but the overall efficiency depends upon the source of the electrical energy and the transmission losses. Where EVs charge during hours of low power demand, such as overnight and at times of the year when there is no shortage of hydro power, then the source is renewable and efficient in terms of substituting for fossil fuel. However, if the source is thermal generation, then the overall efficiency of conversion from stored chemical energy to useful work is much lower. The data in Table 4.1 suggests that if the electricity comes from an efficient, combined-cycle, natural gas-fired power station, then the overall energy use and carbon dioxide emissions will be similar to those created by using the gas directly in a CNG car engine.

A significant potential advantage of electric vehicles is that they can be designed to recover the energy normally lost in braking. Regenerative braking can be used to generate power to recharge the batteries. The use of four hub-integrated switched reluctance motors with regenerative antilock braking has been advocated as the most promising development path for electric drives (Lovins, 1993).

Most systems in regular use have relied on the well-understood and proven lead-acid technology, which has a large existing industrial base, while more exotic battery configurations have been used in research and demonstration vehicles (nickel/iron, zinc/bromine, sodium/sulphur and nickel/zinc). In future, alternative storage systems to batteries may become viable. The use of ultracapacitors is promising. Alternatively electrical energy could be converted to kinetic energy in a high-speed lightweight flywheel and reconverted as required. Both systems would allow rapid draw-off of energy for acceleration.

Existing technology for road vehicle applications is largely based on the separately-excited DC electric motor with transistor or thyristor "chopper" control, a system that allows smooth acceleration and regenerative braking. There are other propulsion options that avoid the need for a mechanical commutator and provide an overall weight advantage (about one-half) as well as a slightly greater energy conversion efficiency compared to the DC motor. For example, several electric vehicle prototypes (including the Canterbury University experimental vehicle) use an AC induction motor and electronic inverter, and these types of propulsion system are expected to provide an attractive solution economically and technically in future. Solar vehicle races, like the Australian rally and the United States Sunrayce are providing an incentive for the further development of efficient lightweight motors and battery systems (and solar cells).

Battery electric vehicles were promoted in New Zealand during the 1970s by the late Dr Byers of Canterbury University. A review of electric vehicle applications in general was carried out in 1981 by the Liquid Fuels Trust Board (Noble et al., 1981). A 1995 state-of-the-art review of EVs and hybrids was recently published in the United States (Sperling, 1995). This review provides an in-depth analysis of electric vehicles for people who want more detail than is provided in this report.

Hydrogen

The "hydrogen economy" has been regarded as a long-term goal by some energy planners and integrated production, storage and use systems have been proposed (see Figure 4.7 for an example). In the future, hydrogen could be reticulated via natural gas pipelines and used to generate power, which could then be transmitted in the normal manner. Hydrogen can be used in conventional internal combustion engines or can be used as a fuel for a vehicle fuel cell that forms part of an electric hybrid engine system. The principal advantage of hydrogen as an internal combustion engine fuel is that it is clean burning, produces water vapour as the main emission product, and produces no carbon dioxide or other carbon compounds (nitrogen oxides, which are formed during high temperature combustion, are still produced).

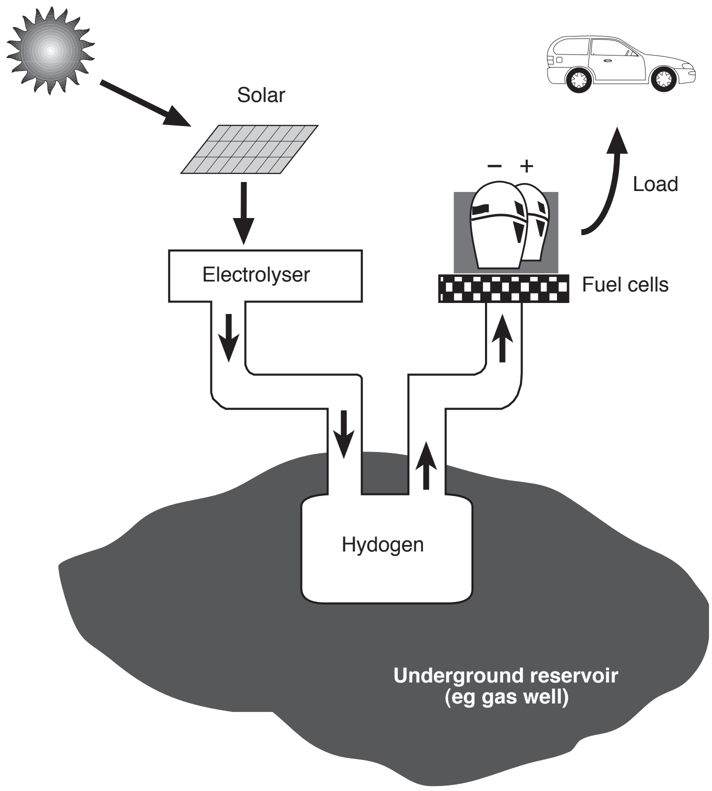


Figure 4.7: Hydrogen energy system (DPIE, 1993)

The clean-burning nature of the fuel makes it highly suitable for use in urban conditions. However, the present constraints on the use of hydrogen as a transport fuel are:

- the method of on-board storage;
- the production of the hydrogen gas; and
- the associated costs of the systems.

Hydrogen can be stored in solid form, as hydrazine, or in liquid form under cryogenic conditions, but the costs and safety of fuel storage are issues still to be satisfactorily resolved. The future use of hydrogen as a vehicle fuel may be facilitated by the development of a sustainable production method. This may lie in solar-powered electrolysis or biochemical methods that use waste organic matter as a feedstock.

4.4 Alternative Engine Systems

Introduction

Road transport is primarily powered by four-stroke diesel and spark ignition engines. Diesel is mainly used in heavy vehicles although its use in cars and light vans is increasing. Most cars have four-stroke engines. These engine types have been developed and refined to the point where they are robust and economical to build. Their efficiency has been steadily improved and, as outlined in Section 3.4, further technical refinements to improve their efficiency and/or reduce emissions are possible. Nonetheless, there is interest in developing alternative engine systems for a variety of reasons: weight and part number reduction, energy efficiency or emission reduction and so that other fuels, such as hydrogen or electricity, can be used.

Two-stroke engines are lighter and have fewer parts than four-stroke engines. They are commonly used in motorcycles, outboard motors, chainsaws and other applications where a high power-to-weight ratio is needed. They are rarely used in cars. In the past, two-stroke engines have been noted for their noise and pollution. They do, however, have some inherently desirable characteristics — they are smaller and lighter than four-stroke engines, have fewer moving parts and lower frictional and pumping losses. Electronic air blast-assisted fuel injection has largely overcome the two-stroke problem of incomplete combustion. Studies have shown that under urban conditions a new generation two-stroke engine can lead to efficiency gains of 15% to 20%. It is possible that in future two-stroke engines will be used more frequently in cars and other light duty vehicles.

The basic thermodynamic cycles that four-stroke engines approximate have efficiency limits that are lower than other potential engine types. Gas turbines, Stirling engines and fuel cells are inherently more efficient than either two- or four-stroke engines. Hybrid engines using electric motors in combination with either four-stroke engines or fuel cells are under development. These engine systems have a range of energy use advantages:

- they can recover energy during braking;
- the combustion engine component can be operated close to its zone of maximum efficiency; and
- electricity from utility grids and/or solar cells can also be used as well as that generated on board.

The remainder of this section provides brief notes on three alternative engine systems: gas turbines, Stirling engines and electric-hybrid systems (internal combustion engines and fuel cell generators).

Gas Turbine Engines

Gas turbine use in transport is generally restricted to vessels and a number of military vehicles, such as tanks. They have a number of potential advantages that make them attractive for motor vehicle use:

- thermal efficiencies over 40%;
- low emissions that could meet standards without exhaust treatment;
- ability to run on a range of fuels, both liquid and gaseous; and
- flexibility with regard to fuel octane and cetane value.

Ceramic gas turbines (CGT) are considered to have the greatest potential for automotive use and the various elements of this technology are under active investigation. For example, in 1990 a number of Japanese agencies started on a seven-year programme of work to develop and evaluate a 100 kW CGT suitable for use in cars and other light duty vehicles (Itoh, 1992). The use of ceramics allows very high temperatures to be accommodated, but at the same time the ceramic components are fragile and susceptible to heat-induced stresses, especially just after startup. Research is focusing on both ceramic material science and engine layout and design to produce a reliable machine.

The Japanese engine is single-shaft turbine with a single-stage centrifugal compressor and a single-stage ceramic radial inflow turbine. The combustion system consists of a ceramic combustor that is fed by a lean pre-mixed, prevapourised fuel supply during idle and at loads up to 30% maximum. Beyond that load level, direct fuel injection forms part of the fuel supply. This arrangement allows emission standards (for NO_x in particular) to be satisfied without exhaust treatment. The compression ratio is 5.0 and the turbine inlet temperature is 1350 ˚C. Combustion efficiency is 99.5%. The exhaust gases pass through a diffuser and a ceramic regenerator that transfers heat to the incoming air stream. The whole assembly is placed in a metallic outer housing protected with thermal insulation.

The fuel economy of cars powered by the prototype engine is better than comparable four-stroke vehicles of the same curb weight. The difference is most marked under steady driving conditions. At a steady 100 km/h, the CGT can provide more than a 50% improvement in fuel economy. This improvement drops to around 15% to 30% (depending on the vehicle comparison) at a steady 60 km/h. Under the Japanese 10 Mode drive cycle (a mixture of urban and steady speed driving), the advantage is typically 20%. While the CGT-engined vehicle has adequate acceleration and speed, the tendency of gas turbine engines to run on after acceleration creates a difficulty that still needs to be addressed.

Volvo has developed a concept car that uses a gas turbine-electric drive and this is described under Electric-Heat Engine Hybrids below.

Stirling Engines

The Stirling engine operates on a closed thermodynamic cycle with one mass of gas being repeatedly expanded and compressed at different temperatures. Figure 4.8 shows the essential working features of a Stirling engine (University of Canterbury, 1994). Unlike an internal combustion engine fuel is burnt outside the cylinders, in a combustor that can use a wide variety of fuels. The fuel burns continuously rather than intermittently and combustion can be carefully controlled to avoid pollution problems, which leads to a relatively clean exhaust. Liquid fuels, gases and even solar radiation can drive this heat machine. The working fluid for a Stirling engine is typically air or helium.

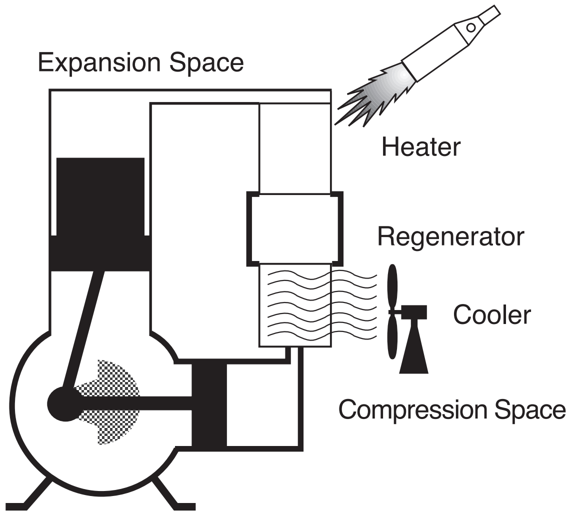


Figure 4.8: Stirling engine schematic (University of Canterbury, 1994)

As the engine has no valve gear and does not involve explosive combustion of fuel, it is very quiet and vibration-free. Many Stirling engines do not require oil lubricants and consequently are easy to keep clean. The engines generally require little maintenance. Theoretically, the Stirling engine has the highest thermodynamic efficiency of all heat engines. With current technology, efficiencies comparable to those for diesel engines are being attained.

Further development of Stirling engines is taking place on several fronts. Firstly, they are seen as suitable as heat engines to drive residential and commercial building heat pumps. More heat is available at the cooling system of a Stirling engine than at the exhaust when compared with an internal combustion engine. This heat can be used as the heat source for a heat pump acting in heating mode. Another use for Stirling engines is as small cogeneration sets for remote homes. In this case, the cooling system heat could be used to provide hot water while the motive power is used to generate electricity. Development work along these lines has been taking place in the Department of Mechanical Engineering at the University of Canterbury. Finally, and the reason they are mentioned here, Stirling engines are seen as potential alternative engines for road vehicles (Huss, 1992).

Electric Hybrid Engine Systems

Electric systems consist of one or more electric motors with power provided from an energy storage device, such as batteries, ultracapacitors or flywheels. These storage devices would be recharged by grid power when the vehicle is not in use and regenerative braking and possibly solar cells when travelling.

Compared with liquid fuels, the on-board energy sources are not very dense and, consequently, electric vehicle range is limited. This weakness can be overcome and many of the benefits of electric vehicles retained if a heat engine such as a four-stroke motor is used as well as an electric motor.

Electric hybrid engines still need power storage and in the medium term this is likely to be batteries. As explained below, the batteries would not be needed for range, but only to provide adequate storage to cover peak demands or generation opportunities (long downhill runs). Only a fraction of the battery mass of an all-electric vehicle would be needed. Some of the weight saving would be lost by the need for an additional engine, which could, however, be very small. The overall result is an engine and energy storage system lighter than a conventional internal combustion engine system and much lighter than an all-electric vehicle system. Consequently, electric hybrids are ideally suited to ultralight and, hence, very energy efficient vehicles (Lovins, 1993).

A wide number of such electric-heat engine hybrid configurations are possible and the two with the most promise are discussed below. Instead of a heat engine, a fuel cell can be used to directly generate on-board electricity for the electric motor using liquid or gaseous fuels. This system and its benefits are also discussed below.

Electric-Heat Engine Hybrids

Internal combustion engines are rarely operated at maximum efficiency. A solution to this problem is to scale down the engine size until the average power requirement and desirable engine RPM for a vehicle coincides with the maximum efficiency island. Figure 3.4 showed the performance map for a 135 HP (100 kW) motor and the line of operation for 8 HP (6 kW), the average requirement for a typical sedan. Figure 4.9 shows the result if the 135 HP engine was replaced with a 16 HP motor (Mendler 1992). The 8 HP power line now cuts through the maximum efficiency island.

If the primary engine is downsized, then additional power is required for acceleration and hill climbing. An electric motor arranged in parallel with the heat engine can provide this power. The electric motor would draw power from storage that had been charged from regenerative braking and generation from the heat engine when vehicle demands were low. This configuration and controls would keep the heat engine operating at maximum efficiency, even when the vehicle was, for example, coasting downhill. The electric motor could be used alone in urban conditions of stop/start operation where emission control is at a premium. Work carried out by Volkswagen on a parallel hybrid diesel electric has shown energy efficiency gains of 20% in urban driving.

The alternative configuration is a series arrangement where the heat engine is used to provide a constant electrical power output. Surplus power goes to storage while the electric motor draws energy from storage for acceleration and hill climbing. In this case, it has been suggested that a small internal combustion engine (e.g. an Orbital derived two-stroke or semi-adiabatic Diesel engine, a Stirling engine, gas turbine or fuel cell) could provide the electricity (Lovins, 1993).

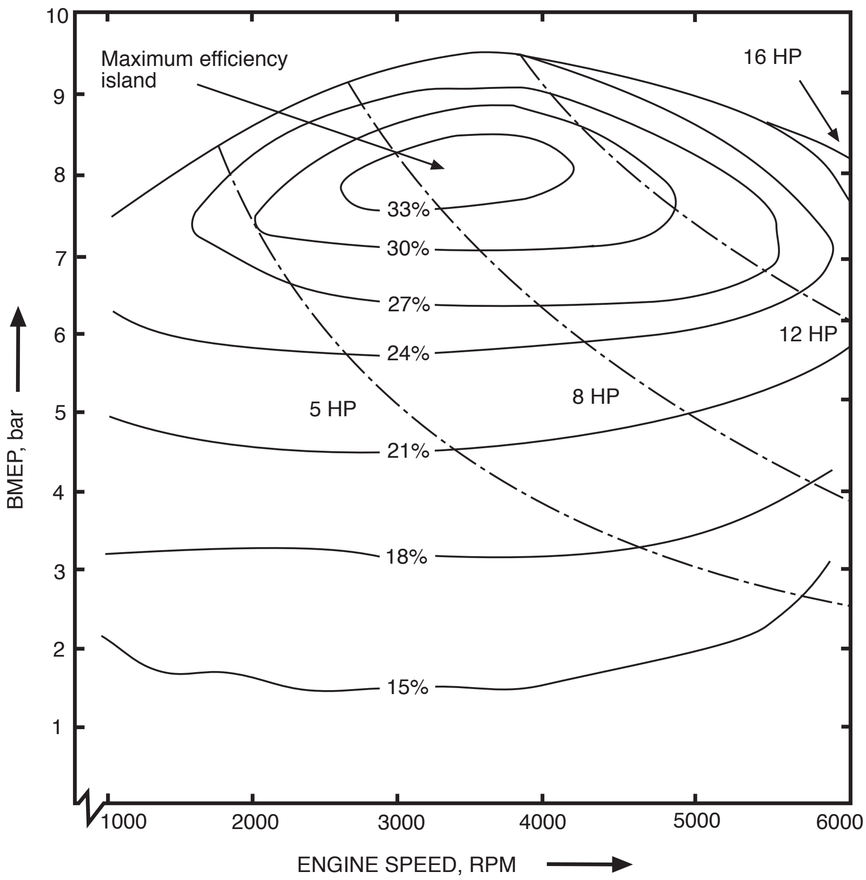


Figure 4.9: Performance map of a 16 HP engine showing average power usage coinciding with maximum engine efficiency (Mendler, 1992)

Volvo has developed an environmental concept car with an electric-hybrid propulsion that uses an aircraft-type gas turbine diesel engine. An electric motor drives the front wheels using power from batteries or the gas turbine, or both. Acceleration is satisfactory (zero to 100 km/hr in 13 seconds) and fuel consumption, at 5.2 litres/100 km at a steady 90 km/hr, is half that of a similar sized conventional car. Presently, the car (which has other special features beyond the turbine engine) would cost about 30% more than a conventional car to mass produce.

In New Zealand, an electric hybrid system has been developed for an Auckland bus. The prototype bus was developed by the Auckland Engineering School, with assistance from ECNZ, using off-the-shelf components as much as possible. The prototype features a variable speed electric drive, which enabled a 132 kW three-phase induction motor to be used. The motor is supplied via a reliable DC/AC convertor drawing on battery power. A small 30 kW CNG-fuelled motor driving a generator extends the battery range. The end result was a bus that could travel at up to 75 km/h, carry 40 people and had a driving range of between 100 and 150 km per charge.

Electric-Fuel Cell Hybrids

Fuel cells are not new (a rudimentary fuel cell was built in England over 150 years ago), but materials science problems and cost have held back their development and use. A fuel cell-powered farm tractor was built by Allis Chalmers in the United States in 1959. At present, they have military and space applications and are also used in a few prototype or demonstration programme urban buses.

The fuel cell relies on an electro-chemical reaction that is set up when fuel is supplied at one electrode and oxygen (as air) at another, the two being separated by an electrolytic medium. The reaction produces an electric current, some residual heat and reaction products. Most fuel cell technology uses hydrogen as the fuel, the hydrogen/oxygen fuel cell being a product of the US space programme. Successful fuel cells have now been developed to use other gases such as natural gas, and gas made from coal (e.g. CO) or biomass (e.g. CH_4).

Fuel cells could prove suitable for buses, trucks, locomotives and marine vessels within ten years. Over the next 15 to 30 years, they could be developed for cars and other light load vehicle applications (Department of Energy, 1990).

The energy conversion efficiency from the chemical energy content of the fuel to the electrical power produced is considerably greater than that for a conventional internal combustion engine and generator set. Fuel cell efficiencies are over 45% and may exceed 60% in future. In the case of the hydrogen/oxygen fuel cell, the reaction product is water, so the system is non-polluting. When other gases are used, the emissions can be limited to carbon dioxide and water. As very high temperature combustion does not take place, NO_x problems are minimal; emissions are of the order of 1 ppm, two orders of magnitude less than for heat engines, which means they can easily meet the proposed strict standards for California.

Figure 4.10 shows fuel cell chemical reactions using a range of potential fuels. Figure 4.11 shows one of several configurations (Argonne National laboratory's monolithic design) for a solid oxide fuel cell (SOFC), one of several third generation cells (Badwal, 1990). Oxygen in the air reacts at the cathode. The oxygen ion migrates through the electrolyte and oxidises the fuel at the anode. The electrolyte is a solid zirconia-based material, and the electrodes and interconnections are all various types of ceramics.

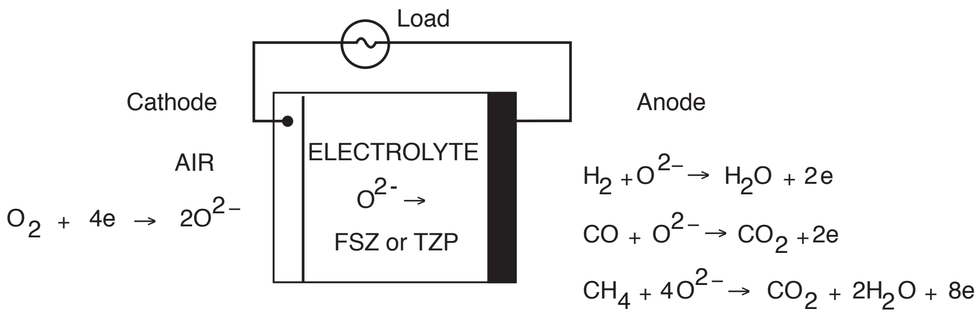


Figure 4.10: SOFC reactions (Badwal, 1990)

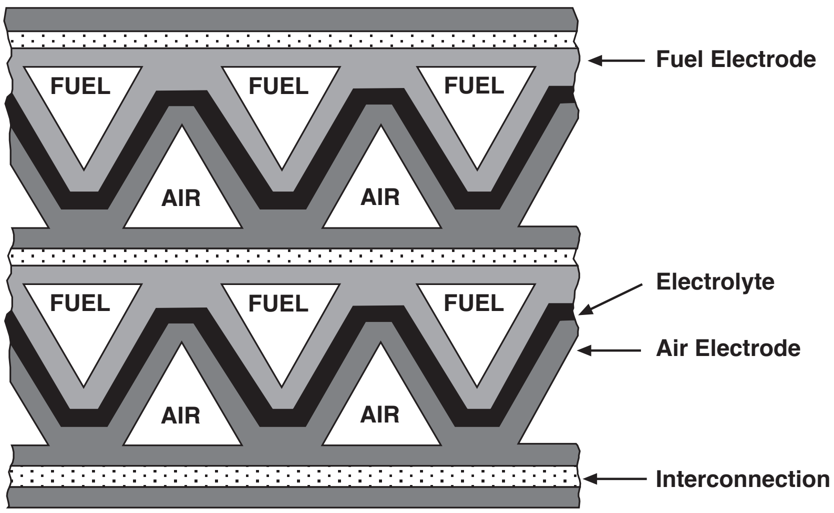


Figure 4.11: Monolithic configuration. A matrix of anodes, cathodes, electrolyte and fuel/air spaces is created in a structurally self-supporting cell.

A SOFC can be operated at atmospheric or higher pressures and the exhaust gases can be used to drive a conventional or advanced cycle gas turbine. Consequently, in an electric-hybrid arrangement, electricity could be obtained directly from the fuel cell and also via a heat engine and generator set. While it may operate at high temperatures (1000°C), the all-ceramic SOFC is relatively safe (absence of corrosive liquids and molten salts) in the event of an accident, an important vehicle consideration.

Phosphoric acid fuel cells technology (PAFC) is the nearest to commercial introduction for civil applications due to concentrated research over 25 years. PAFC technology is being adapted for transport applications (Hagey, 1992). In the late 1980s, the US Department of Energy developed a methanol-fuelled prototype small urban bus. An urban bus was chosen because this application will accentuate emission benefits and the transit route structure facilitated comparison with diesel buses. One of several issues with PAFC systems is safety associated with the phosphoric acid. However, the cell operating temperatures are low at around 200˚C so at least the problem is not compounded by the high 650˚C temperatures of molten carbonate fuel cells. As the latter do not appear to have promise as transport energy convertors, they are not discussed here.

Since 1982, the Los Alamos National Laboratory has been developing polymer electrolyte fuel cell (PEFC) technology for transport applications under the sponsorship of the US Department of Energy. General Motors has now joined this effort. The program aims to develop a proof-of-concept 50 kW PEFC power system for transport by 1997. The concept uses reformed methanol as the fuel and air as the oxidant (a PEFC can also use hydrogen). The objective is a high power density, rapid startup, low-cost fuel cell, all essential requirements for transport applications. For a general overview of US fuel cell programmes and objectives, see Fuel Cell Implementation Committee, 1990.

A PEFC uses a special solid polymer ion-exchange membrane as the electrolyte (note: PEFC is sometimes referred to as proton exchange membrane fuel cells). The cost of this membrane and the high noble metal (e.g. platinum) content of the electrodes make this type of fuel cell expensive. This, together with other issues (Hagey, 1992), has made some commentators sceptical about the future prospects for PEFC technology (Badwal, 1990). Nonetheless, an urban bus demonstration programme is currently underway in Vancouver, Canada, using an advanced fuel cell of the PEFC type that has overcome or avoided these problems. The fuel cell in question has an electrolyte of graphite/solid polymer sandwich construction. The fuel is hydrogen stored in compressed form in cylinders and air is delivered by an on-board compressor.

4.5 Conclusions

The development of alternative fuel and engine technology is an exciting area with many prospects for cleaner burning and more efficient engines. For the most common vehicle engine, which uses the four-stroke cycle, the most likely development over the next ten years is the use of optimised CNG and LPG engines. A light van with such an engine has been developed for commercial use in California and has been certified as meeting that state’s Ultra Low Emissions Vehicle Standard (UVEL). This standard will progressively apply to more and more of new vehicle sales from 1997 onwards. Unfortunately, as other parts of the world take a greater interest in CNG/LPG, New Zealand is in danger of losing its CNG infrastructure.

Within ten years, it is conceivable that fuel cells, possibly combined with gas turbines, will come into use on heavy vehicles. The final drive for these vehicles is likely to be electric, which can provide good torque characteristics and regenerative braking. This innovation will be aided by development of rapid discharge battery or other high density, easily-tapped energy storage systems, such as flywheels or ultracapacitors.

The motor car is likely to become much lighter and more streamlined. As a result, it could be readily driven by an electric-hybrid engine. Efficient two-stroke petrol or lightweight diesel engines will be suitable as the source of on-board power. Later, Stirling engines and, ultimately, fuel cells, could be used to provide electrical energy. Regenerative braking will be a must. These cars are also likely to use solar panels to run accessories such as interior cooling fans when parked in the sun.

The development of alcohol fuels from biomass presents a great opportunity for New Zealand with its vast forest resource and potential to grow energy crops. Alcohols can be used in a wide range of engines, internal combustion through to fuel cells they are also easily stored and have a reasonably high energy density (similar to LPG). While hydrogen has many environmental advantages and can be manufactured from renewably-sourced electric energy (e.g. windpower) and from renewable biomass, its low energy density will probably limit its use for transport for some time to come. Its first commercial applications will probably be in heavy road transport, rail and shipping.

Chapter 5
Road System and Driver Performance

5.1 Introduction

The operating environment for a vehicle, the features of the roading network and the performance of the driver, can be as important in determining energy use as the vehicle technology itself. Chapter 3 identified stop-start driving as one of the major factors that increase fuel use during urban driving. Better traffic control and driver performance (adequate following distances and good anticipation) can smooth out traffic flow and reduce fuel use. Even with vehicle technologies whose fuel consumption is less susceptible to driving conditions, such as electric-hybrid drives with regenerative braking, the road network and driver performance will remain important issues. A road network that is circuitous rather than direct, or that has few traffic signs, will result in less efficient travel than a direct and informative system.

Road System Measures

Figure 5.1 shows the major measures involved in road system design and management to improve energy efficiency. Two subsets of these measures, increasing occupancy by providing public transport and reducing driving distances by urban planning, are discussed in Chapter 6 “Public Transport and Other Options”. The emphasis in this chapter is on the role of traffic engineering to reduce the distance between a given set of origins and destinations and to facilitate public transport, given that a service exists.

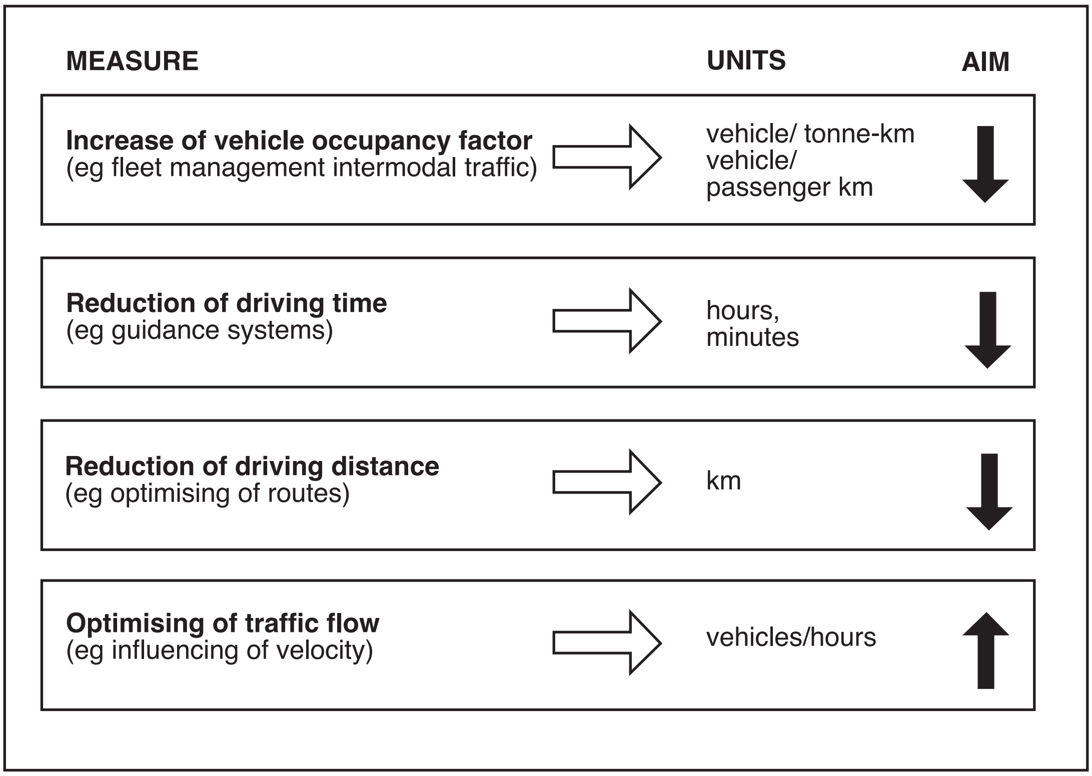


Figure 5.1: Traffic measures for energy efficiency (Huss, 1992)

The first factor, vehicle occupancy, represents an interface between the traffic engineer and wider community policies. From the engineering side, vehicle occupancy can be influenced by creating transit lanes for buses or cars with a minimum number of occupants (car and van pooling is discussed in the next chapter). The operation of these lanes needs to be integrated with the rest of the network. In a sophisticated system, it may be possible to extend transit lane privileges to reduce delays at some controlled intersections, and to provide priority egress from parking buildings fronting busy streets, etc. Corporate policy can affect occupancy through such means as office parking space allocation. Central and local government policy on vehicle occupancy can range from public transport subsidies to coordination of ride share schemes and education services.

Reducing driving time without increasing top speeds can save fuel through less vehicle idle time, avoidance of congestion, etc. Traffic guidance systems are being developed that communicate information to drivers on route conditions and ways to bypass accidents or traffic jams and on optimal speeds (to get the next light green) or safe speeds (in heavy fog).

Traffic guidance systems can provide a dynamic route optimisation but they are only as good as the underlying roading network. As is the case in most countries, there is scope in New Zealand to alter traffic flows, create one-way streets, upgrade roads, etc. so that travel distances and fuel use are reduced.

Sometimes a trade-off will need to be made between reducing distances or reducing travel time. One-way systems, for example, may increase travel distances, but if they are well designed they will reduce travel times (at least during peak periods). As pointed out in Chapter 3, travel time appears to be one of the major determinants of fuel use during urban driving. Nonetheless, it does not necessarily follow that reducing average travel times during peak periods will reduce overall transport fuel use; the fuel implications for all drivers need to be considered.

Road and intersection design and the use of signals can facilitate smooth flowing traffic in a variety of ways. Good lines of sight, for example, enable drivers to enter traffic streams without stopping. The ultimate goal for road transport is to have the average speed of traffic close to the urban legal limit and achieved not through drivers exceeding the limit, but by having minimal stops or crawling traffic.

Unfortunately, this goal could be undesirable for other transport modes such as walking and cycling, and even some road modes, particularly buses. Uniformly distributed, moderately fast moving traffic makes it hard for pedestrians to cross roads, buses to re-enter the traffic stream and for cyclists to negotiate intersections. The result can be an increased bias of urban transport towards car use. Traffic calming and steps to reduce the capacity of roads may encourage drivers to consider alternatives and make these alternatives more attractive. Calming itself need not increase fuel use, but if it does, then mode shifting could more than compensate.

Obtaining uniform vehicle speed may even be counterproductive in terms of car energy efficiency, or not sustainable if an initial reduction in travel times encourages more people to drive. A Californian study (Woodhull, 1992) concluded:

> *On the basis of the fact that a vehicle travelling at a constant optimal speed produces less polluting emissions per mile, traffic flow improvements have been incorporated into plans for reducing air pollution. The approaches are well liked because they seem to offer a win-win situation — faster driving and cleaner air; and no-one loses property, because existing roads are used. Yet consideration of higher order effects — cumulative effects caused by network feedbacks — would indicate that actions to increase traffic speed will normally worsen air quality and increase emissions of greenhouse gases, because these actions increase vehicle miles travelled.*

Reducing driving time, shortening driving distances and improving traffic flow can be achieved by major extensions of the road network rather than just adjustments to the existing system. New motorways, overhead bridges to remove intersections, bypass routes for heavy vehicles etc. can all serve to improve fuel efficiency as well as safety and convenience. Once again, there is a counter argument to the effect that shortening travel times only serves to encourage even more people to live on the urban fringe and commute or make more trips. For example, a recent major study in the UK (SACTRA, 1994) concluded that most main highway building leads to induced traffic. This problem will be most important where the network is, or will be, operating close to capacity, where road users respond strongly to changes in travel time and where there are large changes in travel time. One of several means to deal with this issue and ensure gains are not subsequently eroded is to make sure all road users face the true social cost of their trip. This leads to road pricing concepts, which are briefly mentioned in Section 5.2.

There are points supporting both sides of the debate over whether facilitating car traffic assists energy efficiency, hinders it by discouraging other modes or by inducing additional car travel. Transport systems components are highly interactive, with many feedback paths, and consequently planners and engineers need to carefully examine all the impacts of network changes.

Relative Role of Network Measures

Figure 5.2 shows one estimate of the efficiency gains for Germany that may be possible by acting on the measures discussed above. While the features of that country's road network are quite different to New Zealand's, the figures are interesting as a discussion starting point. There do not appear to be any similar estimates of potential for New Zealand.

The figure shows that each of the measures mentioned above is expected to have a similar impact, although extension of the road network may be the most important in Germany. This could be in part due to the importance of land transport as an export freight mode in Germany and also the shifting pattern of commerce due to political and economic changes in Europe. Nonetheless, this factor should not be overlooked in New Zealand. There are development opportunities in this country that range from new motorways to serve commuters, to strengthening major highways so that they can carry heavier and more efficient trucks. The cautions above concerning induced traffic demand should be noted, however.

The potential gains in driver communication, road routing and traffic control in Germany could reflect the level of urban congestion in that country. Nonetheless, New Zealand cities, or their access corridors, are becoming increasingly congested. The applicability of these traffic measures will vary from city to city. Driver communication may be more applicable, for example, to Auckland than, say, Wellington. The latter has well-defined corridors with few bypass options. At present, radio stations provide a driver communication service in many cities. In Wellington, the advice to many drivers in the event of an accident, excessive congestion, etc. is to delay travel since alternative routes may not be available.

Section 5.2 outlines information and communications technologies that are being developed and that could play a role in improving traffic management and control, and hence the efficiency of road transport. The other major road network factor, namely extension of the road network, will not be discussed further in this chapter. This is because the energy consequences of network changes require individual analysis and the issue is not as amenable to generalisations as communication technologies and driver education. The concept of specially reinforced super highways for truck freight is, however, covered in Chapter 7 "Road Freight, Rail, Sea and Air Transport".

Driver Performance

The vehicle and the road network are two points on the transport triangle. The third is the driver. The driver is often a vehicle owner and as such is responsible for choices concerning vehicle purchase and the type of fuel it uses. Drivers often have discretion over whether to make a specific trip and also make choices that affect their wider transport demand (through decisions on work and home locations).

This chapter is concerned about the performance of a driver once a decision is taken to make a trip in a particular vehicle. The choices that remain relate to the maintenance state of the vehicle and how it is set up, the question of timing and route, whether the driver travels with others or alone and the way the driver operates the vehicle. To varying degrees these choices are, or could be, influenced by public policy. Compulsory emission testing of vehicles could rid the roads of vehicles with very poorly maintained engines. Speed limits help to reduce fuel consumption by prohibiting excessive speed, although the main objective is road safety. Fuel taxes, if high enough, could encourage fuel-efficient driving habits.

Within a given policy framework and available road network, drivers will still be able to exercise discretion that can affect fuel efficiency. This discretion can be influenced by public and corporate driver education programmes. The main focus of programmes that have been implemented to date has been two-fold:

- improve vehicle maintenance and setup; and

- increase driving skills and awareness.

Vehicle maintenance and setup determine the degree to which the energy efficiency potential of the vehicle approaches that inherent in its design.

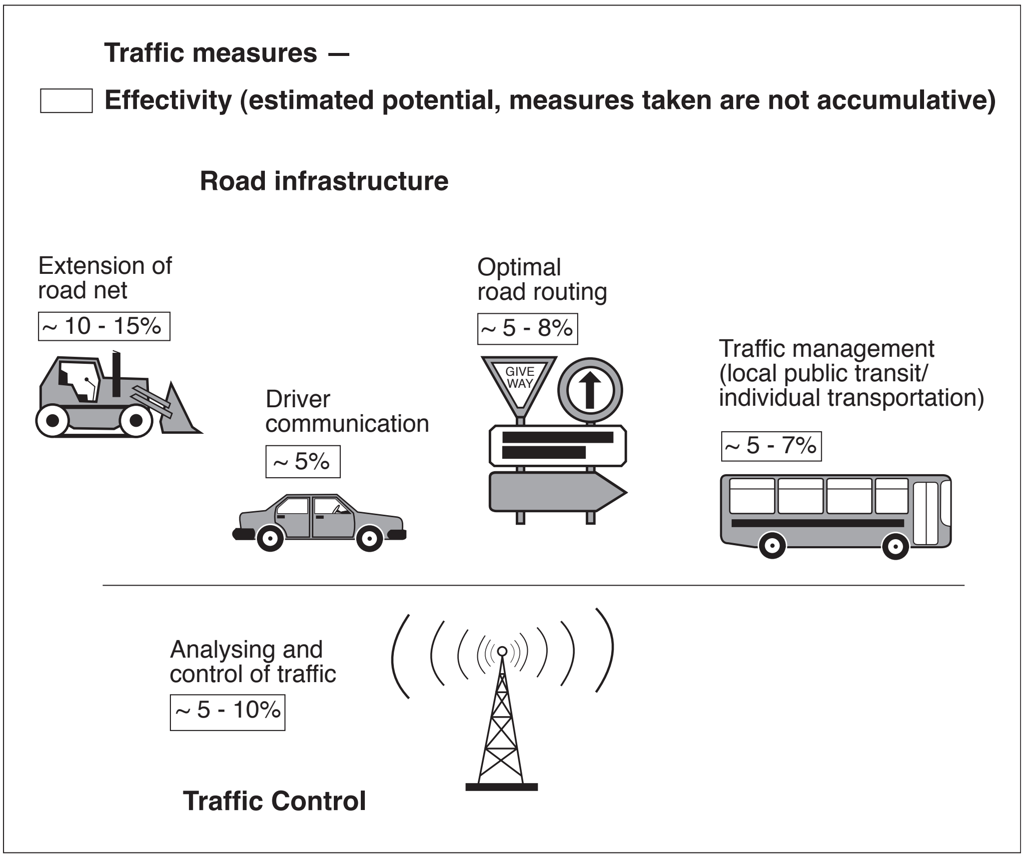


Figure 5.2: Reduction of fuel consumption from traffic measures

While the focus is often on engine maintenance, underinflated tyres and poor wheel alignment can add several percent to the fuel bill for cars and even more for trucks. Setting up a vehicle with rarely-used roof-racks and extra weight (bullbars or large tool kits) also adds to fuel use.

Numerous studies have shown considerable differences in fuel economy attributable to no other cause than driving style. Savings of 10% or more are observed when people drive with fuel economy in mind and these savings do not necessarily come at the expense of travel times. In many cases, there is an increased average speed due to better driver anticipation. The main difficulty is getting people to permanently change their driving habits so that savings are locked in. For the freight industry at least, on-board computer and engine control systems are now available that provide continuous feedback to the driver to facilitate economical vehicle operation.

Section 5.3 provides an overview of the vehicle maintenance and setup factors and driving skills that affect energy efficiency. That section also provides a summary of past New Zealand driver education programmes.

5.2 Information and Communication Technologies

This section discusses a number of information and communication technologies that could assist with traffic control and management. These are:

- area traffic control systems;
- automatic vehicle identification;

- driver information systems; and
- demand response vehicle scheduling.

Area Traffic Control Systems

Traffic signals are an accepted means of reducing traffic conflicts at busy intersections. As control equipment has become more sophisticated, signal installations have been designed to be increasingly responsive to changes in the traffic arrival pattern with phasing that minimises the delays experienced as a whole and by any particular traffic movement.

The next stage from an isolated traffic signal installation is signal linking along an arterial route to create a "green wave", and from this to more complicated optimisation of traffic signals over a grid of streets, called area traffic control (ATC). New Zealand has adopted the SCATS system for ATC and installations are now present in all the main centres and most of the provincial cities.

Area traffic control normally attempts to optimise travel time on the network, that is to minimise delay while observing certain constraints on the maximum acceptable delay to any one traffic movement. Minimising delay, insofar as this promotes uninterrupted traffic flow, is also consistent with minimising fuel consumption. However, minimising delay does not necessarily correspond to minimising the number of stops, and the number of stop/start cycles contribute to fuel consumption. Nevertheless, a well-designed, well-managed ATC system aimed at minimising traffic delay will also be effective in reducing fuel consumption and will certainly be an improvement over an uncoordinated urban network.

In 1975, it was suggested in NZERDC Report No. 27 that 0.8% of transport fuel could be saved by ATC. Transit New Zealand has encouraged the installation of SCATS systems, and it is unlikely that many opportunities exist for new installations that are not already planned. Consequently, any further savings are likely to be small in terms of total fuel consumption. There is the possibility that the optimisation criteria of SCATS systems could be further examined to ensure that the balance between delay, fuel consumption and other costs of vehicle operation reflects their respective economic values.

A remaining problem in traffic control relates to phantom pedestrians. Having pressed the signal button, some people will cross the road as soon as there is a gap in the traffic rather than when signalled to do so. In periods of light pedestrian traffic, car drivers are often forced to stop unnecessarily after the person has crossed. The use of weight sensitive footpath sensors, infrared detectors, etc. to determine if the pedestrian is still waiting have been trialled.

Automatic Vehicle Identification

Electronic tagging of vehicles, generically referred to as AVI (Automatic Vehicle Identification), is useful for tracking the movement of vehicle fleets or of the cargo carried and for automatic charging systems. By monitoring the position of buses, for example, more control can be exercised over the regularity of arrivals to minimise the natural phenomenon of "bunching".

Examples of AVI have been in use for some years as demonstration projects and the technology is now moving into mainstream use. Indeed, the basic technology of a roadside sensor activated by a passive electronic tag on a vehicle is already widely used for low-speed control of access to restricted areas.

However, the greatest interest centres on AVI applications in road pricing, that is charging vehicles for roadspace on a scale that reflects the costs they impose through congestion at particular locations and times of day. These applications place various demands on the technology, in particular on the ability to read and debit on-board payment cards at highway speeds with reliable transaction security.

Road pricing will only lead to increased energy efficiency if potential trip makers have viable alternatives, such as being able to reschedule travel, amalgamate trips for several purposes, share transport or use other modes.

In Europe, the DRIVE Project, an umbrella research programme funded by the EEC, is focused on the application of emerging technologies on transport systems. It includes the PAMELA project, which is developing two-way radio communications between vehicles and roadside beacons for automatic debiting of pre-paid smart cards. Based on the early results of this project, a consortium of interested research/ government/industry participants is undertaking large-scale trials for various applications of the technology in the following countries:

- Sweden (driver information and multi-lane pricing);
- Greece (automatic lane tolling);
- Norway (Trondheim — integrated payment services for urban access control);
- Portugal (Lisbon — car park pre-booking, real time route guidance and account debiting); and
- the UK (Cambridge — congestion pricing scheme).

In the USA, AVI has been in use for some years in route tolling applications (e.g. the Lincoln Tunnel in New York/New Jersey and the Coronado Bridge in San Diego).

AVI was the subject of a session at the 1991 New Zealand Transport Symposium at which the European developments (Jones, 1991) and Singapore schemes (Beng, 1991) were presented and prospects for application in New Zealand were discussed (King, 1991).

Driver/Passenger Information Systems

Information technology is being used for information and advisory systems in road transport. Examples are:

- roadside electronic signage that advises of traffic conditions ahead and recommended driver action, such as speed reduction or diversion to other routes;
- on-board electronic mapping systems that provide guidance on the best route to the intended destination; and
- electronic boards at public transport stops that advise of the time of arrival of the next service.

The fuel efficiency advantages of such information systems for private vehicles lie in minimising wasteful vehicle running through poor route choice and reducing delay by avoiding local traffic congestion. For public transport, accurate information displays for passengers are expected to increase bus patronage, particularly if coupled with increased reliability of arrival time through other public transport priority measures.

An example of such a public transport system is that being piloted in Birmingham, UK, as a DRIVE Project. The 50 buses in the pilot scheme will be equipped with transmitters that will use a satellite link to relay data about their progress to a central computer database, from where the information will be distributed to electronic screens at bus stops. A similar scheme, called "Countdown", has been in use in London, again on a trial basis.

An example of a route guidance system for general road traffic has been under trial in Berlin. The on-board computer receives data from fixed roadside radio beacons (attached to traffic signal installations) on the current status of traffic on the network. From this information, the computer selects the quickest route from the current point to the requested destination. The information is also expected to be of use to haulage firms.

At a more local level, Hoffman and Zimdahl (1991) report on a system that would allow the driver to tap into the signal control system, providing information on when upcoming area controlled signals are next programmed to change, the aim being to allow drivers to modify their speeds to coordinate their arrival with a green signal. The scheme was found to be effective mainly in the off-peak, but did have a negative side in that it encourages excessive speed in some situations.

Demand-responsive Vehicle Scheduling

Transport systems that are responsive to the demand should, in theory, offer a more fuel efficient system than scheduled systems where vehicles will sometimes be nearly empty and at other times will be unable to carry all of the passengers wishing to travel. Demand-responsive scheduling aims to overcome this feature of regular public transport systems by varying both the timing and routes followed, often offering a door-to-door service but at a lower cost than a taxi system.

The name coined for systems of this type is "paratransit" because they fall somewhere in between a stage bus service and the complete time and routing flexibility of taxis and private cars.

While paratransit has long been advocated as an appropriate form of transport for low-density urban areas, its use has been limited in practice by institutional constraints (such as transport union awards and demarcation, and transport services regulation) and by limitations in the control methods for effectively optimising such systems. Progress has been made on both fronts and the use of minibus-size public transport vehicles, trading either as variable route shuttles or as shared taxis providing a transport service, is now more common. They are finding their natural place in the market given their cost structure and the features of service they are able to offer.

5.3 Driver Education and Training

In this section, the emphasis is on measures that may be used to influence the behaviour of vehicle buyers and users without resorting to compulsory regulations or to taxation.

Driver Training for Energy Efficiency

It is well documented that vehicle fuel efficiency can vary by quite a wide margin, depending on the skill and approach of the driver. Over a particular test route, fuel consumption can be minimised by techniques such as:

- anticipation and avoidance of speed changes;
- elimination of unnecessary revving of the engine when stationary;
- driving smoothly through the gears and using the correct gear for the engine load; and
- not travelling at high speed, thus minimising aerodynamic resistance.

Several studies have demonstrated considerable differences in fuel economy attributable to no other cause than driving style. Variation of 20% or more has been found between driving with fuel economy habits in mind and driving aggressively, with a lot of unnecessary acceleration and deceleration and high revving while stationary. Even changing from a normal relaxed style to one characterised by better anticipation and engine management can improve fuel economy by 10%. Savings in practice tend to be lower because not all drivers are influenced by training programmes and, of those that are, few achieve their full potential as efficient drivers.

NZERDC Report No. 27 estimated that 1.6% of domestic transport fuel could be saved through driver motivation programmes (Beca Carter, 1977). Later, a Ministry of Energy demonstration/research programme called "Fleetsave", a copy of a Californian programme "GasCap", was carried out by the Auckland AA and included instruction in economical driving practices to employees of several businesses who drove pool or dedicated cars (Lewis and Bone, 1987). Monitoring of the programme showed that a well-motivated driver could be expected to save around 5% of fuel but that continuous reinforcement was needed, which made the programme expensive.

"Team Tauranga", launched during the era of "carless days", used a community-based approach of driver education and achieved a similar result (NZERDC Report No. 89, Philips, 1989). Another education programme encouraged urban motorway drivers to keep below 80 km/hr (NZERDC Report No. 43, Philips, 1980).

While these demonstration programmes produced only modest results, there is probably scope for inculcating more efficient driving habits as part of a wider driver education programme. As New Zealand drivers have established a reputation for aggressive and inconsiderate driving behaviour, a programme to imprint more responsible habits could have gains in road safety as well as fuel economy. The Land Transport Safety Authority is putting resources into accident prevention programmes and is encouraging community initiatives; consequently there may well be an opportunity for an agency such as EECA to become involved in a co-operative programme.

Discussions with road transport operators indicate that driver variation is a major factor in the fuel economy achieved by their fleets There may be differences between truck types; the comment has been made that some trucks, such as the larger Mack and Kenworth types, are relatively insensitive in their fuel consumption to driver variation, whereas other newer designs show very large differences, depending on the skill of the driver. However, with the increasing competition in the labour market, there is little room for poorly-trained or poorly-motivated heavy goods vehicle drivers, and those who develop a reputation for being "heavy-footed" do not last long in the industry.

Commercial vehicles may also be fitted with trip recorders or on-board computers for self-monitoring by drivers or by the fleet manager, and some companies have made a practice of this for many years using a tachograph.

In the mid-1980s, the Ministry of Energy encouraged the fitting of vacuum gauges to cars as a driver aid for self-monitoring of fuel consumption. These days, on-board trip computers that give instantaneous and trip-integrated readouts can be used for a similar purpose. During the mid to late-1980s, trip computers were fitted as standard or optional extras on some high specification cars, but this seems to have died out as interest in fuel economy has waned.

A modern alternative to the vacuum gauge is needed that is more useful than a simple instantaneous fuel consumption readout. Motorists need to know where their current engine performance is in relation to the maximum efficiency island (see Figure 3.4) and how to get closer to the island through either gear or throttle changes.

Vehicle Fleet Efficiency Monitoring

Operators of vehicle fleets, such as companies and public agencies, may monitor the operating cost of each vehicle as a separate item in their management information system. Increasingly, the computer-based cost accounting packages used by large and small businesses can be adapted to keep close track of vehicle costs, if the management desire is present. The prevalence of petrol cards also allows fuel use to be tracked.

A few companies now specialise in vehicle fleet management to take the day-to-day tasks away from the business itself and these companies have developed extensive databases that can be used to abstract information on the costs of specific vehicle types.

Accurate monitoring of fuel use is not as easy as it seems. There are invariably situations where vehicles are fuelled and the costs or the odometer readings not recorded and it can be difficult to correct for missing or suspect data to allow reliable feedback of fuel consumption.

Indications are that road freight transport operators monitor fuel consumption closely, either by on-board computer or at least by recording fuel consumption and checking at weekly intervals. For the transport industry, cost monitoring is important as vehicle costs are the main expense of the business. For other business enterprises, the company fleet is an ancillary cost and before additional resources are put into more careful monitoring of costs, it has to be demonstrated that the extra effort involved is worthwhile in terms of the savings likely to be made.

A recent UNEP/IEO report on climate change and energy efficiency in industry (UNEP, 1994) reported on a British company with a 40 vehicle fleet that adopted a driver training programme and fleet monitoring system. The firm found that when drivers did their best, fuel consumption fell by nearly 10% and travel times decreased by nearly 7%. The trial also confirmed that bad driving habits are hard to break. Nonetheless, over a year of operation, fuel consumption fell from an average of 38.03 litres to 36.20 litres per 100 km. This meant a savings of £UK17,500 per year, which was more than enough to cover the costs of the training and monitoring programme.

Vehicle Maintenance and Setup

Vehicle setup covers adding weight or extra equipment to a vehicle. Items that add to aerodynamic drag, such as bullbars, roof racks, large mirrors and visors, will increase fuel consumption, especially at highway speeds. These items should only be on the vehicle when they are needed (e.g. when towing a wide trailer in the case of special mirrors). Adding unnecessary weight, such as 4WD vehicles routinely carrying an extra spare wheel, or leaving snow chains in a car when not travelling to a skifield, will also add to fuel consumption.

Poor maintenance of vehicles can lead to unnecessarily high fuel consumption. In particular, under-inflated tyres and poor wheel alignment can become a problem on relatively new vehicles and incur costs in tyre and suspension wear as well as a fuel consumption penalty. Regular maintenance of the fuel/engine/ignition system will also minimise excess fuel consumption, although it is older vehicles with mechanical fuel induction and timing that will benefit the most. As the vehicle ages, wear of moving parts opens up tolerances, leading to energy losses (e.g. through reduced cylinder pressure from worn piston rings and valve seats). Regular changes of lubricant will minimise wear by removing dirt and metal particles and will ensure that the viscosity and general lubricating properties of the oil are not seriously degraded.

Figure 5.3 provides a checklist for efficient operation and maintenance of a truck. Table 5.1 shows the sort of savings that may be possible if a poorly maintained truck is brought up to standard. Note that the use of retrofit devices to reduce aerodynamic drag on trucks is covered in Chapter 7 "Road Freight, Rail, Sea and Air Transport". It is equally important that items not be fitted to trucks that increase drag. Furthermore, how a truck trailer is covered or closed, with and without a load, has a marked effect on fuel economy. This issue is discussed in Chapter 7.

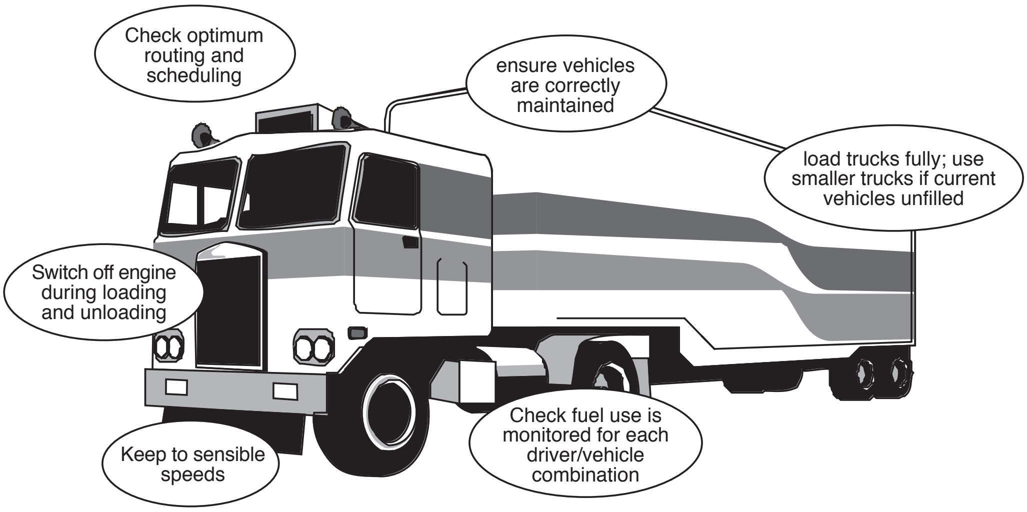


Figure 5.3: Checklist For efficient truck operation (UNEP, 1994)

Check carried out	percentage saving
fuel system for leaks	1
governor settings	2
injectors, pump and fuel condition	8
tyres	3
brakes	2
lubricant	2

Table 5.1: Estimated maximum savings from truck maintenance (UNEP, 1994)

5.4 Conclusions

There is considerable potential for increasing energy efficiency by improving the roading network, but further analysis is not possible in this report as a case-by-case approach is required. New motorways, bypass roads, perimeter roads, bridges creating short-cuts, etc. could be counter-productive in some cases. In the absence of consumption dampening measures such as road pricing or parking restrictions, network improvements could facilitate even greater road use.

Relatively localised network improvements, such as the creation of one-way streets, may reduce stop-start driving and reduce travel times. This could lead to improved energy efficiency, but possibly at the expense of other modes such as walking. It is important that road planners recognise the interconnectedness of the various transport modes and the possibility that improvements in one area can mean problems elsewhere.

This chapter has also discussed information and communication technologies, and driver education and training. The former set covers four areas of interest:

- managing traffic controls to reduce stop-start driving;
- providing information to drivers to enable them to make sound route and speed choices (to avoid hazards or congestion, for example);
- monitoring individual vehicles for purposes of restricting access, levying road user charges and the like; and
- providing information to facilitate public transport.

Generally, with careful planning, information technologies can be used to increase energy efficiency for road users without detriment to other modes. Estimates of the efficiency savings for car drivers from traffic control and routing advice generally fall in the range of 5% to 10%. Information technology also has a potentially important role to play in encouraging public transport by providing accurate assessments of arrival and departure times and facilitating new modes, such as paratransit.

Driver education and training has the potential for quick and significant energy efficiency gains together with other benefits, such as improved road safety. Experience indicates that a sustained programme is needed, however, to ensure the changes in behaviour eventually become permanent. Most drivers can improve their fuel economy by 10%. The fuel economy difference between aggressive and fuel efficient driving can be 20% or more.

Drivers are also responsible for the maintenance and setup of their vehicles, to varying degrees. Drivers can ensure correct tyre pressures and avoid unnecessary dead weight (such as unused tool boxes) and drag-causing equipment (such as roof racks). Vehicle engines should be properly tuned with lubricants and filters changed regularly.

Training programmes for fleet drivers can be reinforced with on-going fuel consumption monitoring systems. Practical experience with fleet-based systems indicate that savings in the order of 5% are possible through changing driving styles and improved vehicle maintenance.

Chapter 6
Public Transport and Other Options

6.1 Introduction

This chapter discusses ways of improving energy efficiency through two related strategies — using passenger transport modes that might be more efficient than motor cars and taking steps to reduce the demand for car transport, or transport in general.

The typical private car is a 4/5 seater, 1.8 litre vehicle, which is frequently operated at a passenger load factor of 30% to 40%. Alternatives to the conventional private car include public transport systems, purpose-designed small urban cars, motorcycles, bicycles and walking. Restrictions on car travel can be part of a parcel of measures to encourage public transport, cycling or walking. The need for travel can also be reduced, or the attraction of public transport increased, by careful urban planning. The use of telecommunications is another means to reduce the need for travel.

Section 6.2 examines bus, rail and light rail public transport. Section 6.3 looks at issues that relate to cycling. Section 6.4 looks at the role of urban planning in shaping transport patterns. Section 6.5 examines demand management through vehicle access controls and use of telecommunications. Finally, Section 6.6 discusses measures to facilitate the use of special urban cars as a new mode.

In some New Zealand cities, walking is an important travel mode. Over 10% of commuter trips in Wellington and Dunedin are made by foot. Road network improvements and traffic control can hinder pedestrian traffic, whereas, with a bit of thought, this problem can be avoided. Positive action, such as installation of verandas, can also be taken to encourage walking. The elderly and children need special consideration. These issues are not elaborated here, but a good overview of the subject can be found in a recent award-winning paper (Frith, 1994).

Mode Comparisons

Encouraging travellers to abandon their cars for other forms of transport, in particular public transport or bicycles, is often regarded as a self-evident way in which energy savings can be achieved. In some circumstances this is correct, as a bus or a train is certainly more efficient on a seat-kilometre/litre basis than a car. However, a true comparison is situation-specific and must take account of the relative load factors achieved in each case, the comparative distances travelled and access trips to the public transport mode.

Table 1.5 showed the comparative energy efficiencies of different modes at typical load factors. Figure 6.1 shows how the energy efficiency can vary with the number of passengers. The data in the figure needs to be updated, but it is sufficient to illustrate a general point — there is considerable potential overlap between cars, buses and rail units and even air travel. When frequent low occupancy and circuitous public transport routes (especially for cross-town travel) are considered, a general case in favour of bus and rail travel is not apparent.

If a circuitous and poorly patronised bus service is going to run regardless of occupancy, then it will usually be energy efficient to gain extra passengers since these will add little to the overall energy consumption of the vehicle and could mean that a car is not used instead. Increasing the frequency of service or adding new routes may not be energy efficient, however, if more efficient modes such as walking, cycling or small cars are feasible.

The aim for public transport has to be to create a service that provides quick and direct travel, convenient scheduling and comfort (physical and mental) in order to attract the patronage that will make the service economically viable and energy efficient. Chapter 8, "Public Policy Options", lists measures that can be used to achieve this goal. One of the topics Section 6.2 of this chapter covers is how the road system can be organised to facilitate direct public transport and convenient scheduling. The issue of comfort often comes down to cost. Subsidies using public funds, transfer payments based on levies to cover car transport externalities, etc., are ways of improving the quality of the service. Better revenues from increased patronage is another, but often a "chicken and egg" situation prevails.

Motorcycles are generally more energy efficient than cars, but not if the car is a compact with two to three passengers. Bicycles are the most energy efficient form of personal transport devised, but carries with them an exposure to the weather, limited luggage capacity and a much higher risk of serious injury in the event of a road crash. Walking has similar benefits and limitations.

Strengths and Weaknesses

For most of us, the journey to and from work is the most frequently made trip. Figure 6.2 shows how modes used for commuting have changed over the last 20 years. The use of cars has increased markedly, while motorcycle, bus and car travel have declined. This presents a major challenge for initiatives to increase public transport use. The first task will be to halt or reverse the declining trend in public transport use.

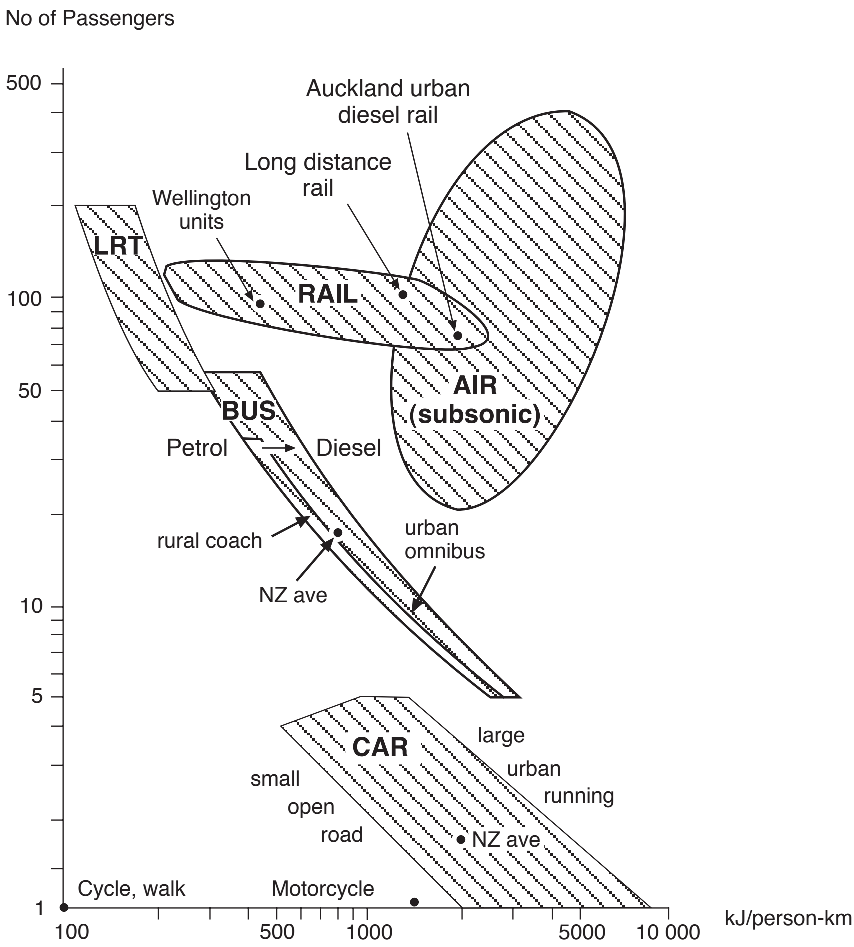


Figure 6.1: Energy intensiveness of passenger modes (Bone, 1994 and Wood, 1995)

The second challenge for public transport is one of reconciling economic imperatives and demand for services outside the commuting peak. Figure 6.3 shows the variation in public transport demand between peak and interpeak periods for bus and rail travel in Wellington. The interpeak periods represent under utilised capital and uneconomic operating costs. On-demand bus scheduling or the use of paratransit can help to reduce operating costs.

Finally, it is useful to recognise that the geographic layout of cities and their climate play an important role in the extent to which transport options, other than using cars, are taken up. The geographic layout is a synthesis of topography and the built environment. For example, Wellington has a high level of commuting by rail, in part because the topography has dictated that urban development take place along two well-defined urban corridors. This is a strength, in that it provides the potential for cost-effective expansion of passenger rail services or development of light rail (it is also a weakness in that it makes the city vulnerable to earthquake and other natural hazard disruption).

Figure 6.4 shows the percentage of commuters walking or cycling to work in the major cities. Few people in Wellington cycle to work due to the weather, the hills and the narrow streets. Another factor is the lack of a well-defined safe lane system for cyclists and the use of intersection designs that do not help cyclists. Wellington should try to address these problems, but at the same time recognise that in doing so it is not playing to a natural strength. One of its strengths is the number of people who walk to work. This could be amplified by encouraging more inner city residential development, providing more pedestrian shelter (verandas and windbreaks), subways at major intersections, etc. Christchurch and Hamilton have a natural advantage for cyclists and these cities could use this strength to greater advantage.

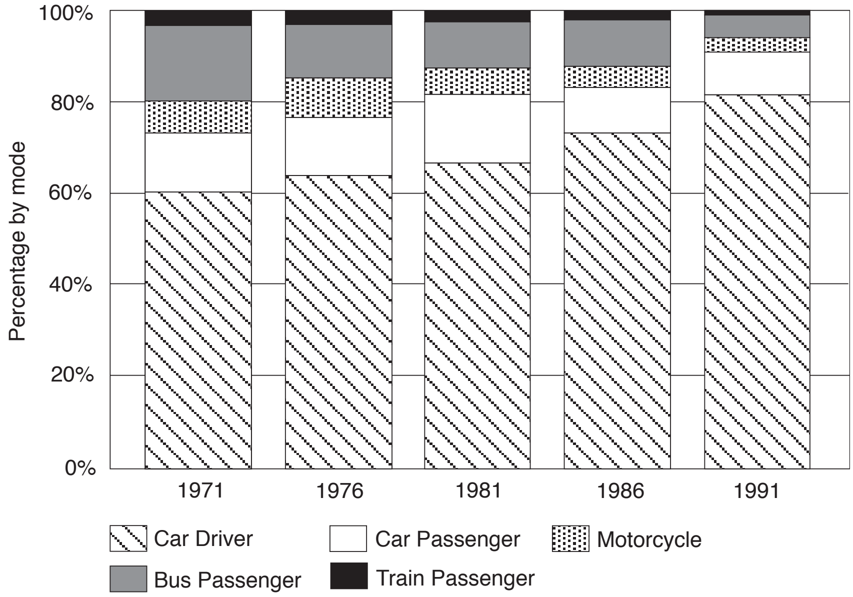


Figure 6.2: Journey to work (NZ Census Data)

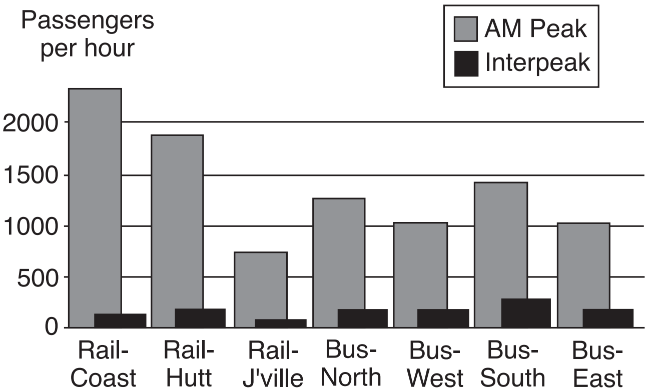


Figure 6.3 : Bus and train travel into the central city (Wellington City Council, 1994)

(a)

(b)

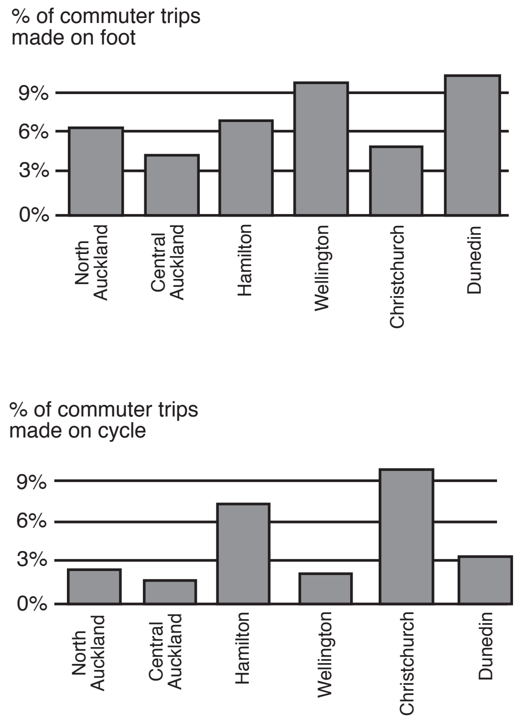


Figure 6.4: (a) Walking in different New Zealand cities; (b) cycling in different New Zealand cities (Wellington City Council, 1994)

6.2 Public Transport

This section considers the trends in public transport use in New Zealand and provides an idea of the contribution public transport could make to transport energy efficiency. The basic strategies for improving public transport energy efficiency are mentioned. The main technical options for better efficiency, other than improvements in vehicles and engines, are outlined. Bus, train and light rail systems are covered.

Current Trends

Census data indicates a general decline in public transport patronage. The graphs in Figure 6.5 show public transport use in different cities and the trend in patronage in the Wellington region. Even though Wellington has several features that favour public transport, reflected in the high level of usage, patronage fell until 1992. Recently, it has stabilised. While the decline over the last ten years is not as great as the preceding decade, the future outlook for growth is not good, either for Wellington or for the country as a whole. A recent study for Transit New Zealand (Travers Morgan, 1990) examined the outlook for public transport in the 1990s and concluded that:

- increases in car ownership are likely to cause a continuing decline in public transport use;
- any further decrease in employment rates, further decentralisation of employment and aging of the population will accelerate the decline;
- changes in social habits and increased suburbanisation could be contributing to patronage declines;
- overall, a continuing decline in patronage of between 1% and 4% per annum for most centres is expected;
- more restrictive parking policies could increase public transport patronage; and
- real fare reduction and/or level of service increases would help to retain patronage, but would require increasing subsidies.

Potential Energy Improvements

As emphasised above, a public transport service may not be more energy efficient than using a car in a given circumstance. Getting more people onto existing services may improve energy efficiency, however, because the services would have operated anyway, and one extra person on a bus or train adds little to the vehicle's fuel consumption.

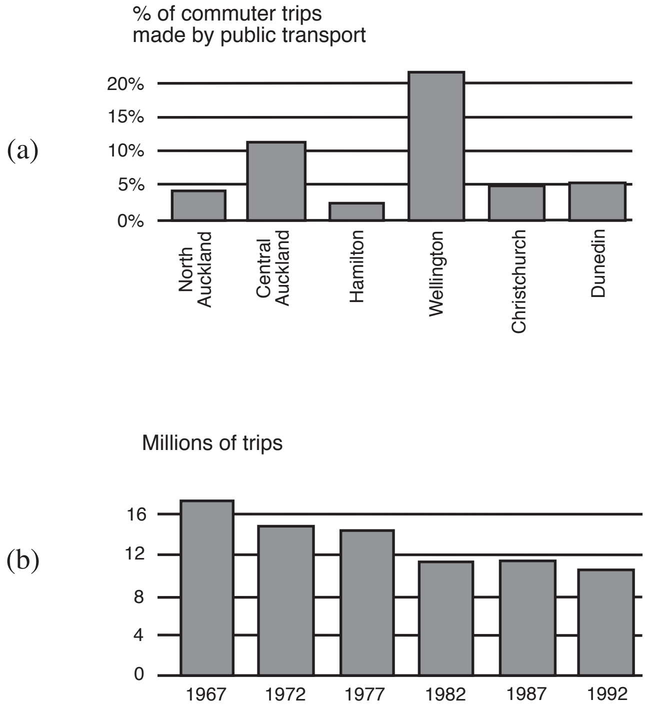


Figure 6.5: (a) Public transport use in different New Zealand cities; (b) declining public transport use in the Wellington region (Wellington City Council, 1994)

Increasing levels of service alone (e.g. increasing the frequency of buses) may increase patronage, but the overall effect on energy consumption can be contradictory. Each 1% increase in service appears to create only a 0.5% increase in loadings (Travers Morgan, 1990). For this reason, extra services will generally have to be backed up with disincentives to car use if efficiency gains are to be made. Even so, not all of the new passengers will have given up a car trip to use public transport; the additional service can create its own transport demand.

The scope for improved fuel efficiency through increased use of public transport in preference to the private car cannot be expected to have a large influence in New Zealand, at least not for many years, as the volume of travel by public transport vehicles is so small in relation to private transport.

However, proponents of public transport would argue that the environmental quality of city centres, particularly Wellington, Auckland and Christchurch, demand that more use of public forms of transport be made in the future. There is some justification for this argument, but the rationale is separate from energy efficiency considerations.

The effects of local area access control and public transport promotion on fuel efficiency are not well documented. NZERDC Report 27 (Beca Carter, 1977) estimated that only 0.07% of domestic transport fuel use could practically be saved by measures to encourage more use of public transport. This estimate was made at a time when public transport patronage was at higher levels than they are now and motor vehicles were less efficient.

A more recent study observed that if the trends in public transport continue, then patronage could be 20% to 30% lower in the year 2000 compared with 1990 levels (Collins, 1993). If a range of steps were taken to halt this decline and public transport was used in a manner that, overall, was 100% more energy efficient than car transport, then transport sector fuel use could be 0.5% lower than otherwise at the end of this decade. A strong effort on demand management was considered essential to achieve this reduction. Demand management would also improve car occupancy and encourage people to walk and cycle. The combined effect of halting the decline in public transport use and demand management was thought to be a 1.5% reduction in fuel use (Collins, 1993).

Future Strategies

Other than constraining car use, the basic strategies to halt the decline in public transport are to promote greater use of existing services, improve existing services (e.g. travel time or scheduling) or introduce new services and infrastructure.

Mass transit systems require high corridor densities to make them worthwhile and require very large capital investment, both of which militate against new investment in these systems in New Zealand. There is, however, renewed interest in less capital intensive systems that support lower corridor flows, such as light rail/ street tram and guided busway systems, which are being introduced in medium-sized cities in other countries where land-use densities are similar to those in New Zealand.

Service Improvement and Promotion

Encouragement to use public transport is in the interests of the public transport operators themselves and usually to the urban planning authorities, who see this as a means of alleviating congestion or the need to invest in costly new roadspace. Consequently, information campaigns and encouragement to use the system is a feature of the activities of these two interested groups. As a general observation, promotion of public transport systems in New Zealand with well designed and effective on-street information on routes, schedules and fares is limited in comparison to those larger overseas cities where the public transport systems serve a larger proportion of the market (and are often heavily subsidised).

As discussed in Section 5.2, information technology can play an important role in providing public transport services. Providing route condition information to the driver can help reduce delays, while a display of accurate arrival and departure times helps passengers to plan their journeys, advise colleagues if they will be late to meetings, etc.

Bus Priority

Another way to improve services is to assign priority to public transport over other modes. Bus priority includes the provision of busways, bus lanes, traffic signal priority, exclusive turning movements for buses and the linking of traffic signals to favour bus movements. For example, the following objectives for buses and light rail were set in Zurich some 20 years ago and appear to have been largely realised (Joos, 1990):

- unhindered trips between junctions, without holdups caused by private traffic, to be achieved by building special lines and separate bus lanes;
- zero waiting time for public transport vehicles at light-controlled intersections by developing a fully flexible control philosophy; and
- system monitoring so that the control centre is aware of timetable or other programme deviations and can remedy the situation or put previously designed measures into effect.

New Zealand is gaining experience with the means to these ends, especially for the first two objectives. A busway is provided on the Auckland northern motorway to allow reduced bus journey times in congested peak hours. Bus lanes have been implemented on parts of Lambton Quay and Willis Street in Wellington with proposals to implement further lanes in the near future, especially on some of the commuter routes. Again, buses gain an advantage by not having to compete with other traffic. This is particularly relevant for buses pulling out of bus stops.

Exclusive turning manoeuvres at intersections, as well as linking of traffic signals to favour bus routes, also occurs in Wellington. Investigations have shown that this can be extended further in the inner city area, producing useful time savings at low cost.

Traffic signal priority has the potential to make major reductions in bus journey times. However, it needs to be acknowledged that where exclusive pedestrian phases occur, then the ability to cut short these phases is limited due to safety considerations.

Bus priority measures have the potential to reduce travel time, particularly at times and locations where there is significant congestion. Careful design of these facilities is required to ensure that they are not frustrated, for example by a carelessly parked vehicle that blocks a bus lane.

Other Urban Passenger Transport Modes

Alternatives to conventional buses and the two suburban rail systems include:

- busways — either as separate rights-of-way for conventional buses or guided systems (both have been promoted in Auckland and Wellington);
- light rail — running on dedicated track or on-street (being promoted for Auckland and investigated in Wellington); and
- taxibus systems — as now operating in Wanganui.

Auckland Busway

Busways may be conventional roadway reserved for bus use or guided systems that use concrete guide-rails and buses fitted with horizontally-mounted wheels running along concrete guide-rails. This allows a narrower track, just a little greater than the vehicle width, than is required for an unguided bus. Auckland has considered both alternatives, but has decided to implement an unguided system. A busway now runs from park-and-ride stops along Auckland's Northern Motorway across the Harbour Bridge and into the city centre.

The Auckland buses are standard vehicles but, being given dedicated "track", they will be able to operate without interference from the remaining road traffic, which will give slightly more fuel efficient operation. However, the main energy efficiency improvement would arise through substitution of a high occupancy vehicle for private transport, assuming that the service does attract car riders.

Whether guided or conventional, busways have the advantage that the vehicles can move between the normal street system and the reserved track at will and so provide a higher degree of flexibility than, say, light rail.

Light Rail

Light rail has a number of transport advantages that translate into energy gains directly, or indirectly via increased passenger satisfaction and, hence, good patronage levels:

- access issues

  — ability to negotiate steep gradients and tight curves (c.f. trains) allowing access to hilly suburbs;

  — end-use pollution free and relatively quiet allowing inner city use;

  — integration with pedestrian traffic/ability to penetrate city precincts;

- performance issues

  — fast acceleration and swift regenerative braking making for good travel times;

  — good safety record on passenger-km basis;

  — considered an attractive mode by potential users; and

  — low floor configuration available allowing ease of boarding.

The main urban centres are in the process of conducting reviews of their urban transport planning studies and some alternative public transport systems have been considered. In Auckland, there is interest in some quarters to establish a light rail system (LRT) using existing suburban rail track with extensions onto city streets in the CBD.

A LRT feasibility study was recently conducted for Wellington (Works Consultancy Services, 1995). This indicated that a LRT system using the three existing rail corridors (Johnsonville, Kapiti and the Hutt Valley) and extending beyond the Wellington City railway station to the far end of the CBD (Courtney Place) would have a satisfactory cost-benefit ratio. Local and regional planning staff are now evaluating the report.

The LRT would be electrically powered and, therefore, involves a substitution of electrical energy for diesel or petrol. Again, the energy conservation potential of the system would depend on the patronage it attracts away from private transport. At face value, though, LRT systems are attractive from an energy efficiency perspective. They can pick up and deliver passengers closer to activity centres, which increases potential patronage and load factors. They are lighter than trains, which reduces energy overheads.

Lack of recent experience with light rail means there is no New Zealand data on LRT energy use. It is possible to infer likely New Zealand performance from overseas experience (Wood, 1995). A study for the London Borough of Croyden, thought to be one of the best available, gives light rail energy use of 2 to 4 kWh per train km. At an average loading of 100 passengers (about a third of capacity) this is 0.02 to 0.04 kWh/passenger km for a heavily graded route.

A report by the UK House of Commons Transport Committee (18/4/91) quotes 0.06 to 0.18 MJ/passenger mile for “full load” and “typical” (33% full) figures, or 0.01 to 0.03 kWh/passenger km. (Note that the original figures in these reports were for primary energy. They have been converted to consumer energy figures assuming a 30% product of generation and transmission efficiencies.

In New Zealand, possible light rail routes are likely to include heavy grades and moderate loadings. Consequently, an end use figure of around 0.04 kWh/passenger km is realistic.

Taxibus Scheme

Transport systems that are responsive to demand should, in theory, offer a more fuel efficient system than scheduled systems where vehicles will sometimes be nearly empty and at other times unable to carry all of the passengers who wish to travel. Demand-responsive scheduling aims to overcome this feature of regular public transport systems by varying both the timing and routes followed, and offering a door-to-door service, but at a lower cost than a taxi system.

The name coined for systems of this type is “paratransit” because they fall somewhere in between a stage bus service and the complete time and routing flexibility of taxis and private cars. Paratransit is a modern update and major improvement over older dial-a-ride concepts and the airport shuttle van services.

While paratransit has long been advocated as an appropriate form of transport for low density urban areas, its use has been limited in practice by institutional constraints such as transport union awards and demarcation, transport services regulation and limitations in the control methods for effectively optimising such systems. Progress has been made on all fronts and the use of minibus-sized public transport vehicles, trading either as variable route shuttles or as shared taxis providing a transport service, is now more common. They are finding their natural place in the market given their cost structure and the features of service they are able to offer.

In the New Zealand provincial city of Wanganui, the local taxi operator gained acceptance for a taxibus system, which can be considered a form of paratransit, as a response to the new competitive tendering procedures introduced for public transport. A similar system was established in Palmerston North. The system operates commercially (non-subsidised) with 10-seater minibuses supplemented with conventional taxicabs. This smaller size vehicle fleet has been able to provide the lower passenger demand public transport service appropriate for smaller centres. There are potential energy savings through better matching of the vehicle fleet to the demand than could be provided by a larger omnibus service.

Car and Van Pooling

Table 1.5 indicates that the average occupancy of motor cars is 1.12 persons. Increasing the occupancy through car pooling — having people with similar origins and destinations share a vehicle — is an obvious energy efficiency strategy. The original motivation for car pooling, however, was to reduce peak hour traffic congestion. In some cities, car pooling is encouraged by setting aside lanes during peak hours for cars carrying three or more people. The faster journey to work and home again creates an incentive for people to share transport.

Carpooling has been promoted in various parts of New Zealand in the past. Congestion on the Auckland Harbour bridge and its approaches, for example, led to an interest in carpooling in the 1970s. The subsequent increase in the bridge's capacity through various other means has partly removed the original motivation. The Automobile Association also played a role in facilitating carpooling during the 1970s. In Lower Hutt, for example, it staffed an information caravan on the Hutt Road for a week and invited motorists to call in and discuss carpooling and pick up a "survey of interest" form. While more than 1000 forms were distributed, only 24 were returned. Of the returns, three groups of two people were matched for carpooling (Beca Carter, 1977).

The overall experience with car pooling in New Zealand is that it is not popular with commuters. It is thought that carpooling is more effective when it is encouraged by an employer, particularly if participation is matched to allocation of car parking where this is scarce. Carrying this a bit further, to where the employer provides a light van to pick up and deliver employees, seems likely to be viable in New Zealand and is, in fact, practised in some industries already.

The use of vanpooling in New Zealand has been studied in depth to see whether there were any major barriers to its adoption (such as Transport Act regulations relating to driver qualifications). The report concluded that there were no significant technical, legal or regulatory impediments to vanpooling with vans of up to nine seats. The major impediments were lack of interest among employers, the small number of people employed by many firms (dispersed trip origins), the generally short commuter trips in New Zealand (people prefer their own car for short trips) and a general resistance from potential pool members to ridesharing in motor vehicles (Phillips, 1985).

6.3 Cycling

Cycling is probably one of the most energy efficient means of transport. The energy intake, as food, is lower per kilometre travelled than walking and some 20 times more energy efficient than the private car. Cycling does not result in air and noise pollution, consumes less material resources and requires less roadspace than motorised traffic. The basic technology and design of the push bike has been in existence for a century and changes are mainly confined to small incremental improvements through the use of modern, lightweight, high strength materials.

Any measures that encourage cycling in preference to the conventional car are, therefore, likely to contribute to improved energy efficiency and reduced consumption of fossil fuels in the transport system as a whole.

Popularity

Cycling has regained popularity in the West in recent years through its associations with sporting and recreational activity, while in those nations where it has been a primary mode of transport, such as Asia, it is losing ground as societies become more affluent and people can afford and demand motorcycles and cars.

Cycling has also become more popular in New Zealand. Those travel surveys that include or target cyclists show quite significant growth, which has persisted over the last 15 years or so. However, in just the last few years, it seems that the growth in cycling may have declined in some places.

Cycling has always had a relatively high profile in cities such as Christchurch and Palmerston North (which have flat terrain), but this has spread to other urban centres where conditions are less naturally conducive and to the rural road network as cycling holidays and sporting events become more popular. Catering for cyclists on rural roads presents particular design and planning considerations as the differences in traffic speed between cyclist and motorised traffic are greater, aerodynamic effects (air blast) are more severe and there is a greater risk of crashes and severe injury.

Advantages and Disadvantages

Apart from its energy efficiency, the advantages of cycling as a mode of transport include:

- it is more efficient in the use of roadspace;

- it is relatively inexpensive compared with owning a car;
- a cyclist can get access to places a car cannot; and
- parking a cycle takes up little space.

Disadvantages with cycling as a regular mode of transport arise from intrinsic characteristics of the mode and from a built environment in which traffic design is largely controlled by the demands of motorised traffic. The intrinsic drawbacks include:

- exposure to the weather;
- limited capacity for carrying luggage;
- the need for a minimum level of physical fitness; and
- range restricted by time and terrain.

Furthermore, the travel environment for cycling can pose problems, such as:

- safety risks (accident) and health (pollution and noise) impacts when cyclists mix with motorised traffic and mutual safety when pedestrians and cyclists mix;
- unsympathetic road layout design, poor surface conditions, road edge obstacles and traffic management and control devices that do not cater well for cyclists;
- lack of consideration from other road users (and conversely complaints from other road users of the poor behaviour of cyclists); and
- lack of parking, storage and security for bicycles in shopping centres, work premises and at other destinations.

Catering for Cyclists

While some countries and cities provide facilities for cyclists as a matter of course in their road and urban planning, this has not generally been the case in New Zealand. Where facilities are poor, there is little encouragement and some strong disincentives for non-cyclists to take up cycling for the first time or, more likely, rediscover a form of transport they last used in their youth.

Generally, cyclists can be catered for and the problems listed above can be dealt with in a manner indicated by studies of particular circumstances. Most New Zealand city and town councils have, at one time or another, undertaken special studies on how to best cater for cycle traffic. However, public authorities considering the needs of cyclists are often faced with the dilemma of an apparent lack of demand, because there are few who cycle at present, and the costs of providing facilities that separate cyclists from other traffic are relatively high. As funds for road work are always in short supply, cycle facilities often lose out to other claims on expenditure that appear to be more pressing.

In 1985, the Urban Transport Council produced a “Guide to Cycle Facilities”, which, according to its introduction, “represents a synthesis of the best overseas and local wisdom on planning and providing for cyclists, adapted for New Zealand conditions”. This 30-page guide covers the physical planning and design of cycle lanes, separated cycleways, routes and networks, including the tricky problem of catering for cyclists at road crossings.

The Cyclist

There are several identifiable groups among the cycling population with very different capabilities and needs. Cycling has historically been a favourite means of travel by schoolchildren and older students. However, road traffic conditions in many parts of the country have become so hazardous that parents are, naturally, reluctant to allow children to cycle to school. Indeed some schools recommend that students do not cycle due to unsafe conditions. It is an unfortunate fact that when a cyclist is involved in an accident, he or she is more likely to experience severe injury than if in a car.

Cycling is currently very popular among older children and the more youthful portion of the adult population as a recreational past-time, including road racing and touring, mountain biking and track cycling. The older person has historically been a user of cycle transport, although the numbers of older people who continue to cycle appears to be declining.

The fact that people with different standards of physical and mental skills and alertness make up the cycling population presents a challenge to planners of facilities. The difference between the expert cyclist and the rest also comes across in the way that those who promote cycling go about their task. There are two schools of thought — the first that motorised traffic must be conditioned to accept and give due consideration to cyclists and share the existing roadspace with them. Some people consider that to achieve this the cycling fraternity needs to take a strong stand in claiming cyclists' equal rights to the road. This is easier when cyclists are present in numbers to enforce some dominance on motor traffic. If motorists and cyclists can learn to coexist, then only minor modifications to existing roads might be needed to achieve a high degree of safety.

The second school of thought is to physically separate incompatible vehicle types — ideally separating cyclists from motor and pedestrian traffic. The construction of reserved cycle lanes and cycleways is the result. However, these are difficult to provide where space has not previously been set aside, except at the expense of reducing the roadspace for motor traffic, reducing the footpath for pedestrians or taking land from adjoining property. There is also the problem of whether reserved cycle track will be adequately maintained as a cyclist requires a surface as smooth as any other road vehicle. And then there is the problem of intersections that, if not dealt with effectively, puts the cyclist back into the traffic stream just at the place that most accidents occur.

Cycling as Part of Dual Mode Travel

Use of the bicycle can extend the range of public transport stops. While a few hundred metres may be a reasonable radius for pedestrian access to a bus stop or a rail station, this can be extended to three kilometres or so if using a bicycle. As with all "park-and-ride", there must be secure facilities to park the access vehicle, in this case a cycle, at the transit stop. Better still, the ability to load the cycle aboard the public transport vehicle allows the cycle to be used to get to the destination at the other end of the journey, effectively extending the range of the public transport system even further.

Unfortunately, opportunities to board cycles on buses and trains have become less rather than greater, while the use of bike racks attached on the rear of cars has increased.

The public transport studies and plans of authorities around New Zealand show little consideration of the opportunity for cycles to play an important role in supporting the public transport market. While some time is devoted to considering pedestrian access times and to car park-and-ride schemes, the humble bicycle seems to slip through the net.

Potential Impact of Cycling on Energy Use in the Transport System

Based on average figures, encouraging a person to ride a bike instead of driving a car will save a similar amount of energy to encouraging two car users to take a bus. This comparison is quite valid if a new bus service is being considered. The cost of facilitating cycle use could be quite competitive with the overall cost of introducing new public transport services or increasing the car carrying capacity of roads.

Cycling should receive more attention in transport planning than it does at present. While it is not a suitable solution for transport of the elderly and has a number of other disadvantages, a combined approach of paratransit and cycling could provide an energy efficient alternative to either more cars or conventional public transport.

Actions to Promote Cycling as a Transport Mode

Neither a complete separation of cycleways from other traffic routes nor insisting that cyclists always be accommodated on the roadway is likely to be fruitful in advancing the use of cycles as a means of transport. To some extent, the popularity of cycling for recreation may have clouded the issue. Recreational cycling is largely undertaken as a separate activity and can take place away from traffic or, if the person is mentally sharp and fit, among traffic. But cycling for day-to-day transport needs to be available to people of a wide range of physical ability, and consequently allowance needs to be made for limitations in physical prowess and judgement skills.

A cycle plan for a city should make use of a range of facilities:

- some dedicated cycleways either alongside roads, or entirely away from the road system, such as through parks;
- some cycle routes where the road layout can be designed with cycle-lanes, or with the innermost traffic lane sufficiently wide to allow for vehicles to overtake cycles;
- appropriate provisions at intersections such as islands guarding right-turn lanes; and
- cycle parking facilities at shopping centres and other public places.

While public transport plans usually overlook cyclists, most New Zealand cities have some form of policy and physical plan for cycle routes and cycle networks, but progress in implementing change is rather slow. Progress on cycling, similarly to promoting public transport, is a “chicken-and-egg” problem. For cycling to regain the popularity for personal transport that it had in the past, a physical infrastructure that has a number of components, many of which are now missing, is required. Without the physical infrastructure in place, there will be little evident cycle traffic demand. Without the evidence of demand, it is difficult to convince authorities of the need for funding.

In promoting cycling, technology and planning knowledge are not constraints. Apart from the Urban Transport Council publication, there are many texts and practical examples from overseas on how to go about planning and educating for increased use of cycling.

Cycling Bibliography

Readers wishing to gather more information on cycling, in the context of urban and transport planning, could refer to the following publications:

American Society of Civil Engineers (ASCE), *Proceedings of a Seminar on Bicycle/Pedestrian Planning and Design*, Florida Dec. 1974.

Auckland Regional Authority, *Auckland Regional Authority Bike Plan*, 1987.

Christchurch City Council, Transportation Division, *Cycling in Christchurch*, 1979.

Friends of the Earth, *Changing Gear - Why and How to Promote Cycling in New Zealand*, 1977.

Geelong Bikeplan, *Streetscape Design Techniques*, Technical Bulletin 4, 1982.

Hamilton City Council, Works Department, *Cycling in Hamilton*, ca 1985.

Hudson, M. *Bicycle Planning, Policy and Practice*, Architectural Press, London, 1982.

Hudson, *The Bicycle Planning Handbook*, Open Books/Friends of the Earth, 1987.

National Roads Board/Urban Transport Council, *Guide to Cycle Facilities*, 1985.

North Shore City, *Pedestrian and Cycleway Strategy,* August 1993.

6.4 Urban Planning and Energy Use

Within New Zealand, the major metropolitan areas have a variety of urban structural forms. These forms are both shaped by and influence the prevalent transport systems in use and, therefore, with the energy used in travel.

City structure is influenced by, among other things, the population size and density, topography, the strength of the CBD in relation to suburban business centres, how well defined the transport corridors are, the cost of travel and the existing level of investment in transport infrastructure (Brennand, 1992).

City structures can generally be interpreted as falling within a geographic-technological triangle (Brotchie, 1990). At one apex is the city with a single major centre. Average trip lengths for such a city will tend to be long and efficient mass transit may be a good efficiency strategy. Another apex is represented by decentralised cities with a number of almost self-sufficient centres. If transport costs are fairly high, people will try to locate near the centre that best meets their needs and consequently trip lengths will be relatively short. The third type of city is one with activities decentralised and dispersed across an urban matrix. This type of city does not lend itself to mass transit systems and could have a high transport energy requirement. This requirement could, however, be significantly reduced by telecommunication interactions (e.g. teleshopping, telebanking and television).

Within any given city structure, there will be opportunities for refinements that will improve transport energy efficiency. Locating shopping and recreational facilities at urban rail stations, for example, allows commuters to link their trip to work with other activities. This can mean that the subsequent trip from rail station to home can be direct and extra trips from home avoided. The finetuning of urban areas and, to a lesser extent, the broad structure of cities will be influenced by future planning decisions.

This section looks firstly at the legal framework for urban planning in New Zealand and then outlines studies that have linked aspects of urban structure to transport energy use. It ends with an outline of an emerging consensus on urban forms likely to lead to low transport energy demands.

Town Planning and Resource Management

The Resource Management Act (1991) is the principal legislation governing urban planning. One purpose of the Resource Management Act is to promote sustainable management of natural and physical resources. Natural resources are defined as “land, water, air, soil, minerals, energy, and all forms of plant and animals”. Physical resources applies to buildings and structures, which includes transport systems. Therefore, responsibilities under the Resource Management Act can be directed towards promoting the sustainable management of cities from an energy perspective.

The Act, as enabling legislation within which resource management issues are identified and appropriate policy responses developed, is a vehicle that can be influential in energy efficiency and conservation. This is, of course, provided that energy use is identified as an issue at the national, regional and/or local level (Allan 1994).

The general duty set out in the Act is to avoid, remedy or mitigate adverse effects. However, the Act is prescriptive — it says what could be done by way of planning but does not require those with responsibility to act in a certain way. The latitude with which the Act can be applied across various regions and local authority territories allows for urban development to continually change and evolve within the framework provided by the Act. These changes are influenced by short- and long-term economic, social and cultural factors.

The main influence of the Resource Management Act on travel demand management is through regional policy statements, which “set the scene” for local authority policies and objectives and district plans. Local authority rules and objectives (contained in a district plan) must not be inconsistent with regional policies and plans.

Opportunity exists for local authorities to take a pro-active role in the integration of land use planning and transportation planning through objectives and environmental performance requirements that recognise “green field” urban development and the benefits of “in fill” in city centres.

Allied to regional policy statements under the Resource Management Act are Regional Land Transport Strategies. The Transit New Zealand Amendment Act 1992 introduced the requirement for regional councils to prepare Regional Land Transport Strategies, which must identify:

- the future land transport needs of the region;
- how to meet these needs, bearing in mind environmental impacts; and

- identify the appropriate roles for all the different transport modes.

Urban Form, Transport Systems and Energy Use

Cities with high population densities, centralised activities and, to a lesser extent, restricted corridor lay-outs, have the potential to use less transport energy per capita than urban areas with dispersed populations and activity locations. Cities with the first set of characteristics lend themselves to well-patronised, economic and energy efficient public transport systems. The use of these systems is reinforced if the city discourages car use by having congested roads and few motorways and does not provide much CBD parking. It could be argued, however, that allowing a situation of high congestion to develop, with the consequent waste of time and resources, is an admission of transport planning failure (Collins, 1993).

The energy/spatial relationship revolves around energy requirements for mobility. The factors that influence this are the size and shape of settlement, the nature of the communications network and the density and interspersion of activities (Owens, 1985). The movement of vehicles and use of transport energy is derived from urban form and its activity patterns. The most consistent feature of land-use patterns found to be efficient, in the sense that they reduce the need for travel, is relatively low physical separation of activities achieved by moderately high densities and by some decentralisation and clustering of employment and services. Figure 6.6 illustrates the form of the paradoxical centralised-moderately decentralised energy efficient city.

The relationship between transport fuel use per capita and urban density has been studied for a number of cities (Newman et. al., 1987). Figure 6.7 shows that low fuel use correlates highly with population density. Other important factors (characteristics of cities with transport demands less than 20 GJ/capita) are highly mixed land uses, high use of public transport, low traffic speeds and restricted provision of parking spaces and other facilities for the motor car. Fuel use increases dramatically as densities drop below 30 persons per hectare, the point at which Newman believes public transport becomes nonviable as insufficient numbers of people live near the transit routes to justify a satisfactory service.

Data for Auckland has been developed (Fitzsimons, 1990) that places Auckland in the middle range alongside Australian cities, which are themselves between the high fuel use/low density American cities and the lower fuel use/high density Asian and European cities.

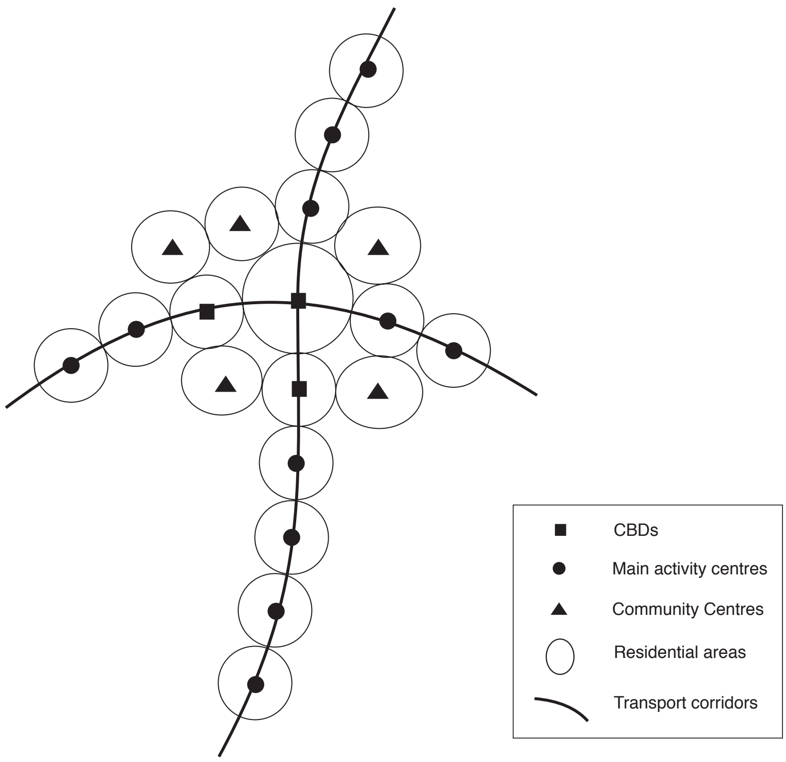


Figure 6.6: Low transport urban form

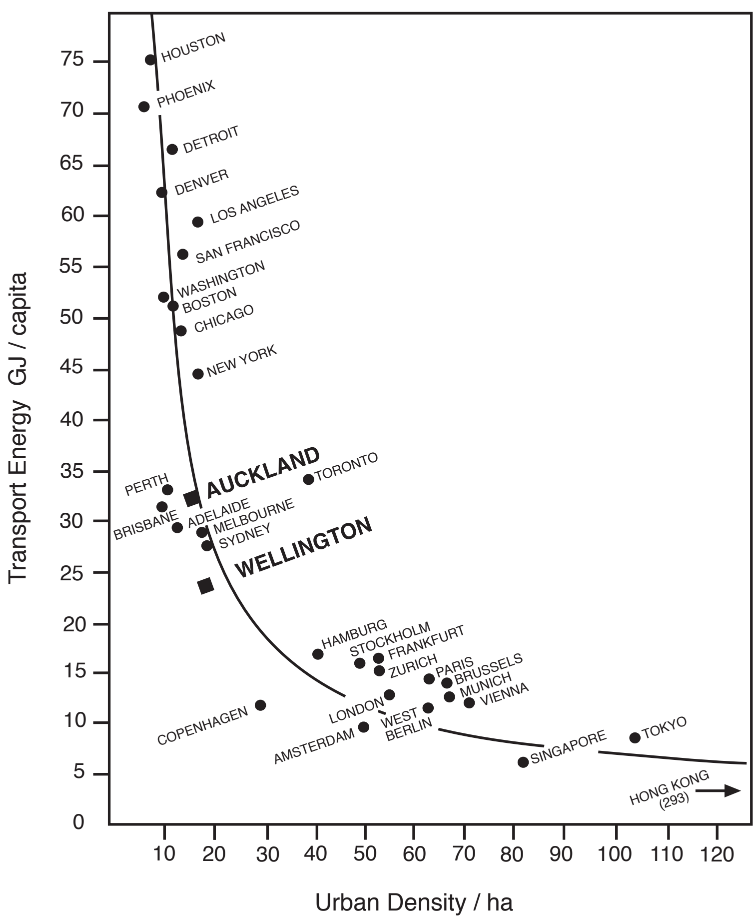


Figure 6.7: Per capita fuel consumption versus urban density in principal world cities (1980), from Fitzsimons (1990), and Wood (1991) after Newman, Kenworthy and Lyons (1987)

Wellington's position on the curve shown in Figure 6.7 would appear to be significantly below that of Auckland and Australian cities on the basis of an average petrol use per capita of 23.2 GJ/capita (Parliamentary Commissioner for the Environment, 1990). Density data from the 1986 census has been used to make an entry for Wellington (Wood, 1991) on the graph produced by Newman et al. (Figure 6.7).

In a paper by Clark (1991), the use of public transport for the journey to work was compared for Auckland and Wellington. It is noted that the relatively high use of public transport in Wellington is due to a compact and dominant CBD that is the focus of regional employment. Furthermore, the topography has assisted in concentrating residential development around well-defined public transport corridors.

Auckland, on the other hand, has a relatively weak CBD with a number of other centres in the region providing strong commercial competition and dispersing employment. In addition, residential sprawl makes it difficult for public transport to capture a significant proportion of the mode share. Similarly, the attractiveness of pedestrian commuter trips is not so high because of long walking distances.

The urban form and nature of the transport systems directly impacts on the energy required for travel in the two cities. Wellington, with a higher proportion of less energy-intensive public transport and pedestrian trips combined with its compact and tightly defined transport corridors, has a lower energy consumption per capita than Auckland, with its greater dominance of car travel.

Future Strategies

There have been further developments in recent European studies on the topic of urban density and transport fuel consumption per head. European research confirms suggestions by Newman and Kenworthy (1991) that transport energy efficiency is not achieved simply by increasing urban density. Various recent studies, for example, have tested four assumptions:

- energy use is directly related to modal share, journey length and vehicle occupancy;
- energy use is directly related to modal share, trip distances and settlement types;
- energy use is a function of density and intensity of land use; and
- energy use is a function of containment for the journey to work.

The results indicate that some tentative conclusions could be drawn on the relationships between transport, energy and settlement patterns. At the general level, it seems that travel distances and trip rates can be reduced if residential areas are related to local jobs and services, rather than developed as dormitory settlements. This confirms earlier studies that multi-centred cities result is slightly shorter commuting trips than cities with a single, large CBD (Brotchie, 1984).

Consistent with this finding, other researchers argue that an urban form that may improve matters is "decentralised concentration" (i.e. some degree of concentration, though not necessarily centralisation of activities), integration of development with public transport facilities and the maintenance of relatively high densities along transport routes (this pattern is shown in Figure 6.6). This approach would promote the development of a number of suburban centres in a large urban area, which would be the focus of improved public transport systems and would help to avoid the congestion and high fuel consumption, associated with a single core. This solution would maintain overall city densities, but would favour public transport and provide for the suburb-to-suburb movements that are neglected by most transport systems.

New Zealand has low population growth and no major urban renewal programmes, and there is, therefore, little opportunity to significantly change existing urban areas to promote greater transport energy efficiency in the short- and medium-term. However, in areas that are experiencing urban growth, such as Auckland, emerging urban form could be shaped in terms of land use/transport integration.

Furthermore, the commercial sector — shopping and services — is constantly renewing itself and adjusting to changing consumer demands. Consequently, opportunities are likely to arise for the relocation of commercial activity around rail stations, bus terminals etc. As noted above, this could reduce urban transport energy demand.

6.5 Transport Demand Management

While urban structure plays a role in the transport energy demand of a city, the way transport demand is satisfied or managed is a crucial factor.

For transport professionals, the conventional goal of demand management is a reduction in peak traffic loads on roads so that existing capacity is better utilised or extra capacity is not needed. The actions taken in pursuit of this goal are aimed at reducing the demand for travel overall, shifting the timing of demand or transferring demand to other modes (or a combination). Each of these actions has a role in reducing the use of energy in the transport system.

Telecommunications is an alternative in situations where the principal underlying purpose of travel is simply to exchange information. The use of telecommunications to reduce the need for travel is discussed below.

Controls on Private Vehicle Use

A variety of techniques are available for travel demand management. Public authorities can, for example, influence the use of vehicles. Annual licensing, which is often used as an instrument for recovering road system costs, can be set high to constrain vehicle use — such is the case in Singapore where road space is at a premium. However, Singapore is an unusual situation and, more often, road space is at a premium only in certain congested urban centres. In these cases, public authorities are more likely to resort to localised area traffic constraints and pricing schemes.

Area constraints can be imposed through rationing or pricing strategies for parking in the area, by establishing cordons and limiting access to vehicles carrying special permits, or by requiring a special fee for entry to the controlled area. An example of a regulatory measure to control access into the city is the restriction on vehicles with odd- or even-numbered plates to certain days in Athens. In the USA, employer-based travel demand management schemes have had some success (Glazer, 1989). Normally instituted to relieve congestion, these schemes are usually paired with incentives to use public transport, such as park-and-ride schemes or free shuttle buses. So far, these forms of area access control have had limited application in New Zealand, although the recent establishment of a central area parking permit scheme for Wellington is a step in this direction.

Many of the measures listed in Table 8.1 of Chapter 8 "Public Policy Options" can be described as demand management via control on private vehicle use.

New Zealand Experience

Historically, New Zealand's track record in traffic energy efficiency and travel demand management has not been consistent. Central government policies such as carless days can be seen in hindsight as "knee jerk" reactions to temporary circumstances that have threatened the security of foreign oil supplies.

Travel demand management has not played a major role in the transport strategies of New Zealand city councils and regional councils until recently. Regional policy statements, developed under the Resource Management Act, provide some guidance towards the implementation of travel demand management techniques. Both the regional policy statements and the regional land transport strategies (developed under the Transit New Zealand Act) often contain policies that might encourage use of public transport modes, improved safety and reduction in direct and indirect environmental impacts. One aim of the policy structure is energy efficiency across the whole transport network.

There are a number of initiatives now underway in New Zealand's larger cities that show that the above policies can result in practical measures. In the Auckland region, there have been two significant developments — a busway in the northern corridor and developments in passenger rail in the southern and western corridors.

In 1989, Wellington attempted to introduce a parking restraint policy that would have limited parking ratios in new building development in the central city. The policy attempted to introduce parking ordinances that would have been among the most stringent in the world. However, the policy was not implemented as a result of public reaction.

Studies have been undertaken in Wellington (Steer et al., 1993) to determine what kinds of travel demand management techniques are appropriate. The conclusions were that road pricing would not be well received and that measures that control the parking supply or price would be more appropriate.

In May 1992, Wellington City Council made public its "Transportation Strategy", which indicated that control of the growth in private car commuter traffic into the CBD is a key policy. A target of limiting morning peak commuter traffic growth to 0.5% per annum over the next 20 years has been adopted, with parking control as the main instrument to achieve this aim. Implicit in the strategy is the need to carefully design the measures so as not to threaten the economy of the central city.

In November 1993, Wellington City introduced its fringe area and central city coupon parking scheme. This scheme targeted commuters who parked all day on-street in fringe residential areas and required these to display a prepaid coupon. Initial results indicate that less people park in the inner city and more people are using public transport (a few percent increase). A direct correlation between the two has not yet been established. Firstly, the previous load factor of cars no longer parking is unclear. Furthermore, some people may be bringing their cars to the city, but parking outside the city coupon parking area and then completing the journey on foot.

In 1994, Wellington City Council proposed new parking ordinances as part of its district plan review. The review is at the stage of hearing submissions on the proposed district plan. The ordinances proposed are less severe in the central city than those in the 1989 proposal but, nevertheless, they would attempt to control parking supply in new building development and discourage the construction of new parking buildings.

The extent to which national, regional and local policy initiatives can influence travel demand is linked to the question of "intervention versus interaction". Free market philosophies and individual freedom to make personal transport choices will remain potential barriers to the effective management of travel demand under existing circumstances. Market forces and personal choice can, however, be linked via the pricing mechanism. Using pricing signals within a free market economy can shift transport demand in the right direction. Wellington's use of a central city coupon scheme may be a case in point (analysis of the effect is needed). Information access is also an important part of a market economy. It may be possible to motivate individuals towards more energy efficient transport modes (both within and between modes) by providing information on transport and energy options and their consequences.

Telecommunications

The potential to substitute telecommunications for travel has long been advanced as a potential measure for energy saving. Opportunities identified include teleconferencing (substituting for business travel), working from home (substituting for work commuter travel) and remote shopping (teleshopping).

Teleconferencing is certainly employed more frequently than in the past, and the widespread use of mobile phones enables personal movement to be more efficiently planned and responsive to needs. As with many technological innovations, these can lead to increased activity as well as more efficient use of time and resources.

Working from home as a substitute for travelling to and from a central workplace requires that the work tasks be separable (ruling out most industry) and not be location-specific (ruling out most primary production). Opportunities are largely confined to the service sector. Constraints against working from home include the isolation involved, as the workplace also serves a social function, the potential problems of supervision and the psychological need to divorce the home and work environments.

Nevertheless, there is increasing opportunity for individual office workers to base themselves at home for part, if not all, of the working week with the availability of computer modem links, automatic call transfer, etc. There is, however, a cost in setting up the "home office" and in providing the additional communication lines to the central office.

There are also recognised psychological/sociological constraints on the substitution of travel by remote communication. A physical presence allows a wider range of expression, implies greater effort and consideration on the part of the visitor, allows the parties to detect nuances in the attitude and atmosphere of the meeting and is more likely to reveal the presence of any audience to the conversation. These advantages are somewhat reduced through a telephone link, even if augmented by video, and more so if substituted by message communication such as pager, e-mail or fax. Each form of communication has a market niche that suits it best and it is unrealistic to expect wholesale replacement of face-to-face contact.

Telebanking is available in New Zealand. Banking tasks are often associated with other activities and travel for these activities will probably remain unchanged. It is not clear whether any reduction in transport energy will result from this technology.

Teleshopping is only starting to take off and it is hard to assess its transport energy implications. It comes in various forms, but the most esoteric under development is the use of virtual reality supermarkets where a shopper's home-based purchases are relayed via a computer and telephone lines to a store computer that orders dispatch. Goods still have to be picked up or delivered home. In the latter case, a store van could be efficiently used to make a delivery round and save fuel per order. As supermarket shopping often involves a single-purpose trip, teleshopping for groceries may save fuel.

6.6 Small Urban Cars

The most commonly sought after mode shift is from motor cars to public rail, light rail or bus transport. New lightweight cars have characteristics so different from the conventional sedan that they can be considered an alternative energy efficient mode, and treated differently to ordinary cars in traffic demand management programmes. The potential for lightweight super-efficient cars was discussed in Chapter 3. The idea of using demand management techniques to encourage the use of small urban cars is discussed in this section.

Walking, cycling and using a car are diametrically opposed in their physical demands, but they share the common features of being (usually) private modes of transport and having the unique qualities of such modes. These qualities are:

- the user can start and finish his or her journey whenever it is convenient;
- access time and distance to the transport service are small;
- the consumer can make cross-town trips and other journeys that public transport cannot hope to service efficiently;
- the user can travel with whom they choose; and
- the user does not have to look up timetables or have fare money or tickets ready.

Consideration of private transport modes is often restricted to walking, cycling and the use of cars. In fact there is a rich continuum between the conventional internal combustion engine, four-seater car, the conventional single-seat pedal-powered bicycle and the pedestrian:

- push scooters, rollerskates/rollerblades/skateboards, etc.;
- push bicycles, tricycles, tandems;
- electric/combustion engine-assisted bicycles;
- electric "mobility" buggies for the aged or less mobile;
- powercycles, motorbikes, motorbikes with sidecars;
- three-wheel micro-cars, electric golf buggies;
- mini-cars — the Mini, Citroen 2CV, Fiat Bambina, etc.

While some of the above have come into and gone out of fashion, the fact that there is a continuum between the unpowered, single-person vehicle and the powered multi-person vehicle needs to be kept in mind when considering future physical planning.

The increasing numbers of older people in the population who have been drivers all their lives and still wish to retain the benefits of some mobility are a case in point. Electrically-powered buggies are a growth market; they operate on footpaths and cross roads but are not really taken into account in our present street layout design or in traffic education and traffic planning. Neighbourhood traffic precincts can be suitable for the use of small, buggy-type vehicles and this is discussed in the case study below.

Encouragement of alternatives to the standard passenger car is one potential method of improving fuel efficiency. The typical car on the road in New Zealand today is about 10 years old, 1.8 litres engine capacity, has the capacity for four or five passengers, but has an average load factor of around 30% to 40%.

For the majority of running, particularly in urban areas, a smaller vehicle would provide the load capacity and performance required. However, it is an observable fact that small cars are becoming less, rather than more, common on our road system. For many individuals and families, the car has to be a multi-purpose vehicle and it is the maximum loading and performance requirements that influence the purchase decision. It is mainly households that can support two or more cars that are most likely to buy a smaller vehicle. Without an incentive, even these households are likely to avoid cars of very small size.

Lovins et al. (1993) makes the case for a coming generation of plastic composite ultra-light cars driven with hybrid petrol/electric drives. Using advanced but proven technology, these vehicles could achieve 1.6 litres/100km. The body shell would still be able to carry the normal complement of passengers and would have similar crash resistance to steel body vehicles (see Chapter 3). A concept small urban vehicle need not, however, be modelled on the conventional four-seater pattern. Given reasonable affordability, a single or twin in-line seater would be suitable for a large amount of urban running. Vehicles of this size would not require the lane width, or parking space, of a conventional car. This advantage, as well as the energy efficiency benefits, justifies the provision of incentives for such vehicles. The incentives could include remarking roadways, providing express lanes and discounting parking charges, etc. In most cities, motorcycles and bicycles already enjoy free parking.

Some commentators (e.g. Sperling, 1995) see a future for lightweight compact neighbourhood electric vehicles (NEVs). These are not suitable for motorway travel, but can keep up with normal urban traffic (to 70 km/h). A range of NEVs are manufactured in the United States, Europe and Japan. A variation of the NEV concept is station cars. These would constitute a car pool for use out of a transit stop. Several US transit operators and electric utilities have formed a station car association and are trialling the scheme. One of the common concerns with very small lightweight vehicles is their compatibility with heavier, often faster, traffic. The case study below shows how this can be achieved.

Case Study -— Palm Desert

Under Californian law, golf carts were only permitted on streets with speeds limits of 25 mph or less and then within 1.5 miles of a golf course. A survey of Palm Desert residents indicated that many would use their golf carts for local travel if allowed to do so. State laws were changed to allow a golf cart demonstration programme in Palm Desert. For local travel, a golf cart must be fitted with basic safety equipment, pass a city inspection and the owner must take part in an orientation meeting. The cart is then issued with a permit that allows it to travel on designated rights of way within Palm Desert. Sperling (1995) reports on the system:

> *A three tier system of right-of-ways was developed for licensed golf carts. They are allowed to travel in mixed traffic on any street with a speed limit of 25 mph or less, ... in separate designated lanes on certain streets with higher speed limits (in some places these lanes are shared with bicycles); and on golf cart paths completely separated from vehicle right-of-ways (several such paths have been built, with plans in the works for additional ones). Meanwhile, special traffic signs and signals are being refined to educate golf cart and motor vehicle drivers about the new infrastructure. Palm Desert is an object lesson in how NEVs could be accommodated in local communities. What is learned there and in other locales experimenting with small vehicles will be valuable when it comes time to design and regulate NEVs...*

6.7 Conclusions

This chapter has discussed a range of alternative transport modes to the conventional private motor car. In deciding whether to facilitate one mode over another through planning and public policy initiatives, the individual circumstances of each city needs to be examined. Cities have varying strengths and weaknesses that can affect the economics, acceptability and practicalities of promoting public transport, walking and cycling, and these need to be recognised.

Public transport is usually held to be far more energy efficient than cars, but this is not universally true when load factors, circuitous routes and other issues are considered. Certainly, if there is a commitment to running a particular public transport service, then gaining extra passengers will usually lead to energy efficiencies (extra passengers will have little effect on a large vehicle's energy use). However, adding new routes or services, which may be justified on a range of grounds, may not always confer energy efficiency benefits.

During off-peak periods, minivans, taxi vans and various forms of paratransit are likely to be more energy efficient than a poorly loaded 40-seater bus. Paratransit is a modern update and major improvement over older dial-a-ride concepts and airport shuttle bus services. This mode is under development overseas using advanced information technologies. Its precursors are evident in New Zealand in the form of the Wanganui and Palmerston North taxi bus schemes.

In the medium term, conventional public transport does not hold the key to markedly improving the efficiency of passenger transport in New Zealand, although it could make some important local differences. This is because any changes would be made on a small base; patronage levels are low and public transport is a minor energy user compared with private cars. The trend in patronage is generally down, but some areas are experiencing modest increases.

The first step for public transport is to get load factors up, both during peak periods and at other times. This can be achieved by discouraging the use of cars and improving the quality of the public transport service.

Means of achieving the latter include assigning buses priority at intersections and along special lanes, and the use of information technologies to provide better schedule reliability and passenger advice on real arrival and departure times.

Light rail has a number of advantages that make it an attractive transport option. It has the potential to be energy efficient and, importantly, to achieve satisfactory patronage levels and run economically in Auckland, possibly Wellington and perhaps one or two other main centres. In terms of national energy use, light rail will make only a small difference, but it could confer important environmental benefits and improved energy efficiency for cities that find it a suitable option.

This chapter has not covered walking, although it is an important mode for commuter trips in some cities. Steps can be taken to facilitate walking and a reference has been provided as a lead-in to this topic. Cycling is another very efficient transport mode. While not all New Zealand cities are well suited to cycling, there is little doubt that more could be done to encourage this mode of transport. A cycling-road design and town planning bibliography has been provided, together with an overview of the main issues raised by this subject.

There is a division among both cyclists and planners as to whether the best approach is to try to separate cyclists from motorists or to facilitate better co-existence via traffic calming and education of the two classes of road user. Either approach is likely to be better than dealing with cycling as a transport afterthought.

Urban planning has the potential to integrate transport systems and the pattern of settlement and activities in a way that reduces travel demand and/or improves energy efficiency. Only a few areas of New Zealand are experiencing rapid urban growth and for most cities the pattern of development has been well established. Nonetheless, the lessons coming out of studies of urban forms and transport energy use may be useful as cities are fine tuned and gradually redeveloped. The energy benefits will be modest in the medium term, but will be permanent once achieved and would be an important contribution to making cities more sustainable.

The urban form that seems to require the least transport energy is one where activities are concentrated at several main centres rather than a single dominant CBD. This layout seems to minimise trip distances without creating the need for an excessive number of trips. Ideally, these centres would lie along corridor routes with sufficient urban population densities to make public transport systems well patronised and commercially viable.

This chapter has also covered transport demand management, via such means as encouraging public transport or discouraging private car use. The use of economic instruments such as road pricing is discussed in Chapter 8 “Public Policy Options”. The New Zealand experience is mainly with providing road priority for buses, such as the busway on Auckland’s northern corridor, and parking restrictions, such as the coupon parking scheme in Wellington. Both measures appear to be successful in reducing inner city congestion, which was their primary goal rather than energy efficiency.

The need to travel at all can be reduced by the use of telecommunications. Teleconferencing and telebanking are now widely available services. Many people work from home all week or on some days. Teleshopping is being trialled and may be become more widespread with the development of virtual reality technologies. At this stage, it is difficult to quantify the potential effect of these technologies on transport demand.

Finally, the development of small urban cars and their transport system facilitation was discussed. These vehicles are sufficiently different from the conventional car to warrant classification as a separate mode. In the future, lightweight, fairly low speed “neighbourhood” vehicles could find a place in the transport milieu. As well as being energy efficient, such vehicles would confer the benefits of private transport without the level of congestion, noise and the other externalities caused by conventional cars.

Chapter 7
Road Freight, Rail, Sea and Air Transport

7.1 Introduction

This chapter covers the potential for energy efficiency improvements in New Zealand road freight, rail, sea and air transport. It starts with an elaboration of the issue of freight mode shifting as a means to reduce energy use, an issue introduced in Chapter 1. Table 7.1 provides general data on the energy intensity of freight modes, based on an Australian study. Generally, rail and sea transport are more energy efficient than road transport, but a number of factors need to be considered when making comparisons.

Rail transport in New Zealand is likely to be more energy intensive than in Australia due to more frequent steep grades. The average energy intensity of rail freight in New Zealand appears to be around 0.8 MJ/t-km (EECA, 1995). This figure is the weighted average of efficient bulk trains (e.g. coal) and general freight. A typical energy intensity for heavy commercial vehicles would be 2 MJ/t-km (Beca Carter, 1994), a figure between the performance of articulated trucks and rigid trucks. The average for all commercial road freight is around 3.3 MJ/tonne-km (EECA, 1995).

An important point that comes out of Table 7.1 is the variation that can be masked by average figures. Articulated trucks can be more energy efficient than branchline trains. In some cases, rigid trucks and trailers may also be competitive with branchline trains. New Zealand experience suggests that articulated trucks can be as energy efficient as general rail freight. Road trains are also a very efficient form of road transport, but are not suitable in New Zealand due to steep grades and tight curves.

Mode Type	Energy Intensity MJ/Net-tonne-km
Bulk trains	0.3
General freight	0.6
Branchline trains	1.7
Coastal shipping	0.1 — 1.4
Utes and panel vans	20.0
Rigid trucks	2.5
Articulated trucks	1.0
Rigid plus artics	2.0
Road trains	0.5
Air transport	15.0

Table 7.1: Energy intensity of freight modes (adapted from Close, 1991)

On a tonne-km basis, rail moves less than 20% of the freight transported by land in New Zealand. Rail transport is not a practical alternative for many freight movements such as cross city traffic, short rural hauls or movements between centres not served by rail. The present limitations of the rail freight infrastructure, particularly the geographic extent of the network, could be remedied, but it is uncertain whether such extensions could claim energy efficiency improvements as part of their benefits, except in special cases.

Rail and road freight can be fairly compared, and they do compete on long distance freight (similar haul distances and type of freight). Independent research in Europe (Catta) and the United States (Batts) indicates that rail has limited or no energy efficiency advantages over road in the cartage of most types of freight over distances of less than 500 kms. In New Zealand, long distance line haul truck operations with high load factors achieve efficiencies close to those of rail (Bone, 1994). If the improvements outlined in Section 7.2 are made to road freight, then, in general, rail will have little advantage on long distance freight by road.

The one exception may be freight railed along the North Island Main Trunk line. Since this line was electrified, its overall energy efficiency has improved markedly (even allowing for thermal power generation). From both an economic and energy efficiency perspective, it is important that truck use between main centres along or close to State Highway 1 in the North Island pays its way.

Truck and rail should compete on the same economic footing. At present, rail has to make a return on capital whereas there is no explicit capital charge for the use of roads. The Land Transport Pricing Study, discussed in Chapter 8 “Public Policy Options”, is looking at whether road users pay the full cost of providing infrastructure together with enough to cover externalities such as accidents and environmental impacts. Preliminary results indicate that present revenues (fuel excise, road user charges, etc.) cover the infrastructure costs, but whether the costs are correctly distributed between road freight and other users still needs to be resolved. The issue of externalities is also still being examined.

Table 7.1 shows a wide variation in the figures for coastal shipping. Roll on/roll off vessels (RoRo) lie at the higher end of the scale (1.0 to 1.5 MJ/t-km). Bulk carriers (cement, oil, etc.) operate at the intermediate level (0.5 to 0.7 MJ/t-km). The most efficient form of freight transport is tug and large barge, which can achieve figures less than 0.1 MJ/t-km. In the New Zealand context, this form of transport can be used for shipping logs from forests adjacent to waterways (e.g. the Marlborough Sounds). It is also suitable for other bulk cargos, such as coal.

Tug and barge is little used in New Zealand, but may be used in future as part of hub and spoke sea transport systems (see Section 7.4). If that is the case, then New Zealand freight transport will have returned to its roots — the main freight mode during the early period of European settlement was coastal shipping using flat-bottomed scows that could cross over river bars.

Coastal shipping competes with either rail, road or both, depending on the circumstances. Recent reforms of New Zealand ports has placed coastal shipping charges on a true-cost basis, in that port charges should include a return on capital. Shipping has a natural advantage over road and rail in that the right of way comes relatively free — it does not have to be constructed and maintained (although the cost of navigation aids, search and rescue and other contingencies need to be met). For coastal shipping to be able to compete fairly, road transport must also pay its true costs. The Land Transport Pricing Study is, once again, very relevant to this issue. At the same time, it must be appreciated that the economics of road transport and its energy efficiency is affected by the present limitations on the road network. Section 7.2 outlines a heavy transport routes study that addresses the issue of whether it may be advantageous to strengthen roads and bridges in order to increase maximum heavy vehicle weights.

Air freight is the least efficient freight mode. Nevertheless, road, rail or coastal shipping is not a suitable alternative for some goods. This is freight where cost is secondary to speed of delivery, either because it is essential information (e.g. documents), perishable or urgently awaited by a client (e.g. vehicle parts). In some cases, the item may require special handling that the couriers linked to airlines can provide. Some of the freight will be transported by air because a cost-competitive system has been developed that integrates courier van pickup/delivery and air freight. This type of freight could be shifted to another mode if the same level of service could be provided.

Three key points come out of the above discussion. Firstly, no freight mode is universally superior to all others. Comparisons have to be made with care and on a case-by-case basis. The full transport system needs to be considered from origin to destination, including all mode changes.

The second point is that before public policies are adopted to favour one mode or system over another in a particular case, the results of fair competition should first be observed. This means getting all forms of freight transport to pay their true costs. Fuel costs are a fairly important component of overall costs, and in a highly competitive environment, freight operators will need to look carefully at energy efficiency opportunities.

Finally, it is important to do two things. Each mode needs to be made as efficient as possible. Then, rather than treating modes as alternatives, adopting an integrated approach is suggested. For example, rather than having public policies that favour rail over road for a particular route, it may be more beneficial to look at integrating road and rail services as a means of increasing rail freight. This could involve vehicle scheduling, the use of container systems that facilitate ready mode transfers, etc.

7.2 Road Freight

Heavy road transport is effectively deregulated in New Zealand. There is now more long distance road freight than was the case before deregulation (1985) and there has been amalgamation within the transport industry into larger operating enterprises. The limits on gross weight have been increased to 44 tonnes, compared with 39 tonnes in the past. While the distribution of vehicle size has changed over time, the total number of trucks in service is similar to 20 years ago (around 66,000 trucks over 3.5 tonnes).

The main parameters that affect energy efficiency in this sector are the proportion of very heavy vehicles, tare weight versus maximum weight, aerodynamics and load factor. The relationship between maximum vehicle weight, axle loads and road infrastructure, and the engine technologies employed are also important. Chapter 1 noted that heavy vehicle fuel efficiency may have improved by 20% over the last 10 years, due largely to improvement in load factor, changing from petrol to diesel engines and, to a lesser extent, the use of lighter alloy bodies and aerodynamic fairing. The average energy demand of all commercial road freight movements may have improved 7% over the same period (EECA, 1995). The information presented below indicates that further efficiency improvements are possible in the future.

Heavy Vehicle Improvement Opportunities

Table 7.2 shows the estimated variation in payload and load factor with truck size (Beca Carter, 1994). The larger vehicles have higher average annual load factors. Table 7.3 shows the estimated changes in load factor between 1975 and 1991 for different gross vehicle weights (GVW). There appears to have been little change over time for the lighter trucks. Where possible, shifting loads to heavier, long-haul trucks may improve efficiency, but many of the lighter trucks will be needed for across town or short-haul rural deliveries. Even in the heavy truck sector, there is further scope for improving load factors.

	Gross Vehicle Weight (GVW, t)	WIM Mean Weight (t)	Tare Weight (t)	Mean Payload (t)	Maximum Payload (t)	Load Factor (%)
2 axle van	11.0	4.8	3.7	1.1	7.3	15
2 axle truck	13.0	7.7	4.4	3.3	8.6	38
3 axle rigid	21.0	12.3	7.6	4.7	13.4	35
4 axle rigid	26.0	17.1	10.0	7.1	16.0	44
5 axle artic	36.5	24.9	11.9	13.0	24.6	53
6 axle artic	39.0	29.3	14.4	14.9	24.6	61
7 axle artic	42.8	33.4	15.1	18.3	27.7	66
8 axle artic	44.0	35.4	18.5	16.9	25.5	66

Table 7.2: Truck size and load factor, 1992 (Beca Carter, 1994)

Another way to improve efficiency is to increase maximum payload by decreasing tare weight. Generally, flat bed trucks have a lower tare weight than a van, tanker or bulk carrier because of the latter's heavier body. However, streamlining loads on flat bed trucks is difficult. The weight of van, tanker and bulk carriers can be reduced by using aluminium alloy and improved integrated steel body designs. Some operators have invested in alloy wheels to reduce gross mass and rotational inertial losses.

Table 7.4 shows the distribution of truck body types from a commercial vehicle monitoring report (Transport, 1989). About 14% of trucks have a van-type body, another 15% are bulk carriers (sand and gravel, milk and petroleum, etc.) and a further 15% are open bodies (stock crates are taken as part of the load). The 44% in the mixed body type covers curtainsiders, flat-bed trucks and smaller vans.

GVW, t	Maximum Payload		Mean Load Factor (%)	
	1975	1991	1975	1991
5	3.0	3.7	20	20
10	6.7	6.8	22	23
20	14.1	12.9	31	36
30	21.5	19.0	40	48
40	-	25.1	49	61

Table 7.3: Maximum payload and load factor (Beca Carter, 1994)

	Petrol (%)	Diesel (%)	CNG (%)	LPG (%)	Total No. (%)
Mainly Enclosed Van-type Bodies					
Refrigerated	6	90	4	-	899 (6%)
Furniture	5	94	0	1	610 (4%)
Route	8	92	-	-	578 (4%)
Bulk Materials					
Bulk	1	99	-	-	2241 (15%)
Open-type Body					
Logging	-	100	-	-	316 (2%)
Stock	3	97	-	-	1525 (10%)
Heavy Haul	-	100	-	-	384 (3%)
Mixed-type Body					
General	5	91	1	2	6332 (44%)
Other	12	85	-	2	1170 (8%)
Mainly Small Vehicles					
Courier	35	26	17	22	461 (3%)
Mail	88	12		-	33 (0%)
Total:					14,550 (100%)

Table 7.4: Distribution of truck types, 1989 (Beca Carter, 1994)

It has been estimated (Beca Carter, 1994) that one-third of heavy vehicles have a cost-effective opportunity for substantial body weight reductions (20% or more), and a further third have the potential for minor reductions (up to 10%). The incentive to make these changes would have been created with the start of deregulation starting in 1985. Changes would depend, in part, on retiring older vehicles and trailers and may require 15 years to complete. On this basis, there is still likely to be significant numbers of vehicles that are tare overweight compared with modern replacement options.

In 1972, around 70% of heavy trucks were petrol powered (heavy vehicles were those over 2 tonnes GVW). By 1982, the percentage had fallen to 38% and analysis of the 1993 vehicle register shows the current proportion to be 16.5% (heavy trucks are now defined as those over 3.5 tonnes GVW). The change over to diesel is largely complete for heavy trucks. The small vehicles entries in Table 7.3 indicates that a large proportion of vehicles between 2.0 and 3.5 tonnes GVW are still petrol powered. Replacing petrol-powered light trucks and vans with diesel-engined vehicles in future would make a small improvement in freight transport fuel use.

Annual utilisation is an important parameter as it plays a role in the cost-effectiveness of retrofitting energy efficient equipment to trucks (e.g. streamlined fairings and lightweight wheels). For light commercial vehicles, the annual utilisation has remained relatively constant, at around 17,000 km (for petrol vehicles the figure is thought to be lower). At the very heavy end of the range, utilisation remained around 35,000 to 40,000 km per year until 1986/87. With deregulation — the removal of quantity licensing — this figure has risen to almost 52,000 km per year. In the intermediate weight groups, a number of factors (e.g. changes to vehicle configurations) make it difficult to discern trends, but typical utilisation would be 20,000 to 30,000 km per year.

Utilisation and load factor are linked. Reducing the number of vehicles, increasing the load factor and travelling more kilometers per year per vehicle are all likely to lead to better operator economics and energy efficiency. The energy efficiency gains come about through less energy overheads per tonne-km of freight and the improved cost effectiveness of investment in efficiency technologies. The technology options range from engine systems through to road infrastructure improvements. The following ways to improve the energy efficiency of road freight are discussed below:

- freight brokerage systems;
- heavy transport route options; and
- aerodynamic fairing of truck and trailers.

Freight Brokerage Systems

Road freight operations in New Zealand are still spread among a large number of companies, even though there has been considerable consolidation over the years since route licensing was exchanged for a quality licensing system. Optimal organisation of the trucking fleet to meet the pattern of freight demand should lead to higher load factors overall by reducing the extent of part load and empty running. The question is how this can be achieved within a competitive industry.

At present, a company or individual that wishes to transport goods will either do this using their own resources or will choose a transport operator. Often, a regular shipper will have a contract with an operator, or possibly with a number of individual owner-drivers. In either case, the shipper has to make his selection without an overall knowledge of the state of demand for freight transport or of the supply availability. The shipper may not know, for example, that a particular operator is looking for a backload and could, therefore, offer a better freight rate.

The answer to improving this situation would be to introduce a freight brokering service for road transport in a similar way to shipping services. Freight forwarding companies already provide this service to some extent, but, with the technology now available through communications and computer systems, a nationwide data exchange could be set up through which shippers and transport operators could better match demand and supply.

Heavy Transport Routes

Trucks in New Zealand are currently restricted to a maximum weight of 44 tonnes and a load of 8.2 tonnes per axle. Suggestions have been made by the transport industry to increase the maximum weight to 60 or even 70 tonnes. At the present time, tractor units may have engines up to 500 HP and this output is considered adequate to pull heavier loads. Vehicle frontal area would probably increase little, if at all, and vehicle tare weight would not increase proportionately with heavier loads. Consequently, increasing maximum vehicle weight has the potential to improve fuel efficiency (and reduce the number of heavy trucks on the roads).

Increasing vehicle weight could be achieved by adding extra axles, increasing the maximum axle load or a combination of both. Permissible axle loads overseas are usually higher than in New Zealand. In Europe, for example, loads are typically 10 to 12 tonnes per axle.

Increasing the maximum weight or axle loads raises a number of issues related to the road infrastructure. Bridges may need strengthening to carry heavier vehicles and pavement deterioration may accelerate with higher axle loads. Additional pavement deflection with heavier axle loads, and the consequent increase in total rolling resistance, may erode some of the potential energy efficiency gains. It may be cost-effective to upgrade bridges, reinforce (and possibly stiffen) pavements and strengthen road shoulders, with payment for these improvements coming from higher road user charges (or another user pays system).

This raises the issue of whether all or only the most heavily-used roads should be upgraded, and if only some are upgraded, determining the most equitable way of recouping additional investment and maintenance costs. Transit New Zealand is in the process of commissioning a heavy transport routes study to examine the economic, engineering and safety aspects of permitting heavier vehicles to use state highways.

Aerodynamics of Heavy Vehicles

Heavy trucks and buses have a much larger frontal area and generally a more square, less aerodynamic shape than the typical car, particularly forward control designs (engine under the cab rather than in front). The principles for reducing aerodynamic drag for heavy vehicles are the same as those for cars: reduce the frontal area and improve streamlining.

During the late 1970s when energy conservation awareness was high, New Zealand bodybuilders began to market add-on air vanes and fairings to improve the aerodynamic efficiency of van body trucks. NZERDC Report No. 27 estimated that such devices would save 0.1% of domestic transport fuel. The size of the market will have increased significantly since this 1977 report as long distance road haulage has expanded, and there is probably further scope for investigating aerodynamic improvements to truck bodies.

A development and demonstration project involving TNT Express Ltd. in the United Kingdom (CADDET, 1993) identified how to retrofit an articulated heavy vehicle in a cost-effective manner to achieve optimal drag reduction. The test vehicle was a 25-tonne laden weight forward-control articulated truck. The study showed that fuel consumption could be reduced by 16%. The company operates two trailers for each tractor unit. The total cost of retrofitting two trailer units and one tractor unit was £UK 3000. The average truck in the fleet travels 193,000 km per year. The payback period for the streamlining retrofit was 0.8 years.

Wind tunnel model testing indicated the best location and shape for the retrofit items shown in Figure 7.1. A reduction in drag of just over 40% from the baseline vehicle figure was inferred from the model studies. The features adopted in the demonstration vehicle were:

- a three-dimensional cab roof fairing which attaches smoothly to the top of the trailer box and guides the air up from the cab roof, (1);
- vertical panels extending the sides of the cab to seal the gap between the tractor and trailer and to enhance the effectiveness of the roof fairing (2);
- side skirt or valence to close the gap between the ground and the trailer body (3);
- a fairing on the front of the trailer body to encourage the airflow to attach smoothly to the sides and top of the trailer box (5);
- rounded top corners on the box body to avoid flow separation in cross winds (6);
- boat-tailing the rear of the box body by means of a sloping roof and rear lower fairings (4,7); and
- other small improvements, such as relocating the rear lights.

Wind tunnel testing also showed the usefulness of an air dam on the tractor to improve the air flow between the ground and the underside of the tractor unit (an air dam came as a standard item on the demonstration tractor). Track testing and computer simulation suggested that 85% of the fuel savings were due to streamlining the tractor and 15% due to streamlining the trailer. The costs of retrofitting the trailers was two-thirds of the total cost. The highest benefit:cost ratio would, therefore, be obtained by dealing with the tractor alone. The payback period for the trailer component of the retrofit may be a bit long for some operators to contemplate. The side-skirts on the trailer have advantages other than fuel savings, however, as they improve the look of the vehicle, reduce spray in wet weather and reduce cleaning costs.

It should be noted that cab roof fairings could be counterproductive if used when the trailer is disconnected or the load (e.g. a container) is removed. A fairing that self-stowed when not needed could be a helpful innovation.

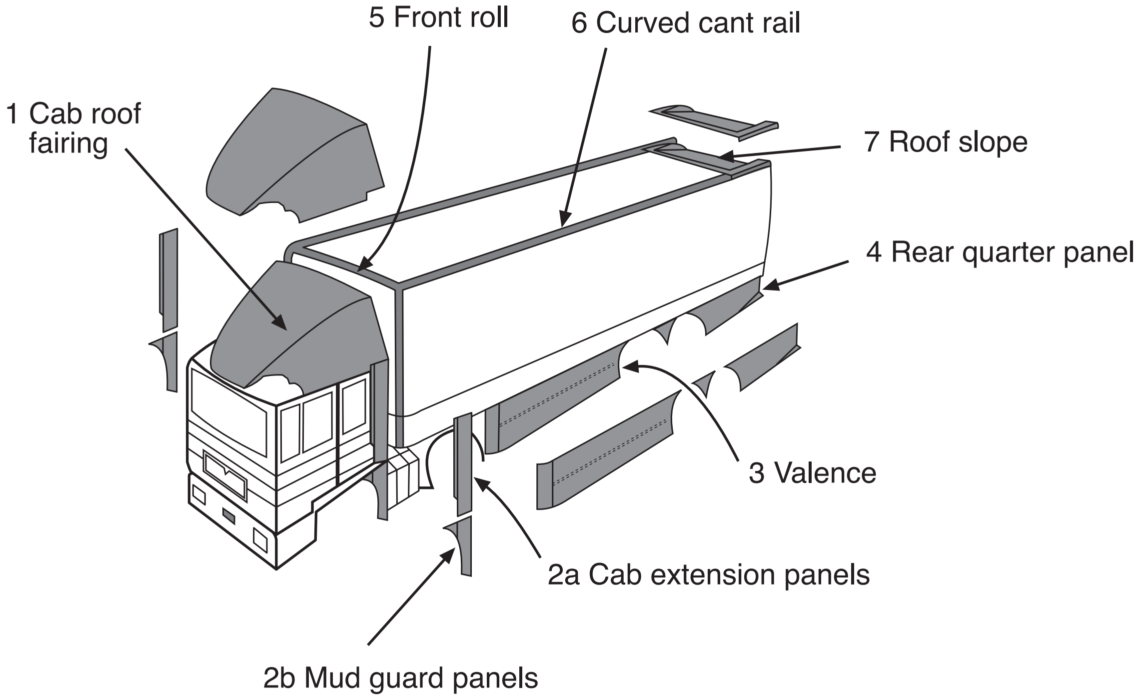


Figure 7.1: Truck streamlining components (CADDET, 1993)

Effect of Load on Drag

The aerodynamic drag on a truck and trailer unit will vary according to the load (full, empty or partially loaded) and how this is covered. Figure 7.2 shows the variation in drag from the basic unit, a bulk material body with an open top and closed tailgate (Energy Authority, 1985). At least 15% of trucks are of this type (Table 7.4). Typical loads include quarry materials, wood chips (or mill slab) and coal. The base truck in Figure 7.2 was assumed to be travelling at 80 km/hr. Its potential load capacity was 38 tonnes GVW.

Simply opening the tailgate while driving (2) with no load will reduce drag by 16%. If this is not practicable, then a tailgate fairing will provide some benefit (3).

Having a full load (4) will reduce drag by 19% and covering the load, or the empty trailer, with a flat tarpaulin (5) will reduce drag by 20%. Low loads without a tarpaulin (6) means less drag than with an empty trailer, but the reduction is far less than with a full load. Having a tarpaulin, nose fairing and full trailer side skirts (7) provides the greatest drag reduction.

The lessons are simple. Try to operate with a full load if the trailer has no tarpaulin. When empty, open the tailgate or use a tarpaulin over the top of the trailer. For long haul highway driving, consider full aerodynamic treatment (7).

New Zealand Experience

New Zealand transport operators appear to have a varied experience and differing views on the merits of aerodynamic retrofits (Bone, 1994). Some operators feel that they are not necessarily cost-effective, and in respect of certain trailer retrofits this may be true. Some operators also consider that other fuel saving measures (such as driver training) are more fruitful and so apply more attention to these. The economic benefits of aerodynamic treatments will be greatest for trucks travelling high annual kilometres predominantly at highway speeds. Part of the problem with the acceptance of retrofits by some operators may be unreasonable expectations of good returns under adverse conditions, such as low annual usage, low speed or grade-dominated routes. Better provision of information to the industry on the degree of retrofit appropriate to different circumstances could address this issue.

For example, some trailer types preclude the use of air spoilers — the air flow to front-mounted refrigeration units can be blocked for instance. Many truck trailer bodies produced in New Zealand are now moulded with rounded edges to provide a degree of streamlining. One bodybuilder estimates that 50% of dry goods trucks or 25% of all heavy trucks have some sort of wind deflection device fitted. Log trucking, projected to increase markedly over the next ten years, appears to be a prime candidate for aerodynamic improvement. Fairing panels to reduce the gap between the tractor and log trailer should be considered.

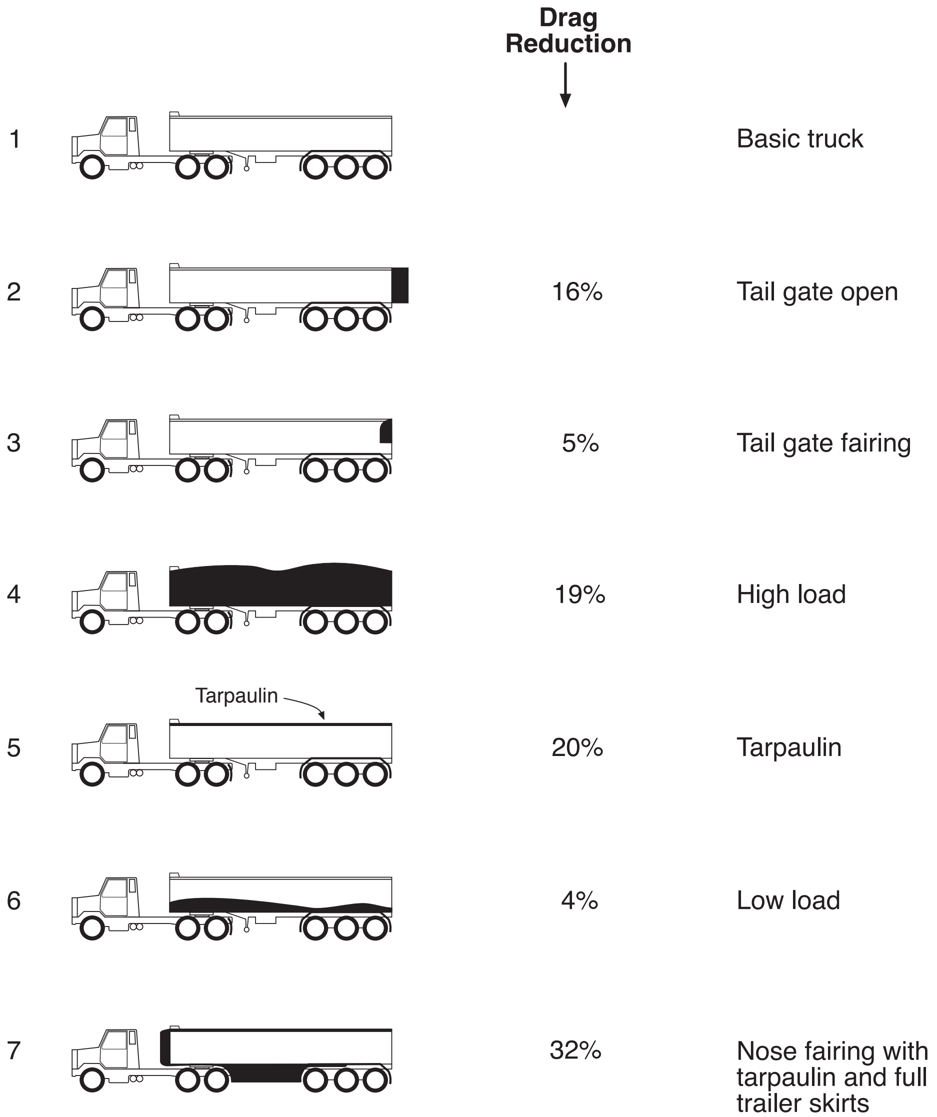


Figure 7.2: Drag effect of load and trailer treatments (Energy Authority, 1985)

It should be noted that if drivers use the increased power available from streamlining to increase speeds, fuel savings will be offset. It is notable that the New Zealand log trucking industry has adopted a code of practice for drivers that calls for adherence to speed limits.

Multiple Units and Buses

The energy to overcome aerodynamic drag per tonne-km of freight moved can be reduced by using heavier, longer trucks. Road trains, common in parts of Australia, are comparable in efficiency terms to long haul trains, which is in part due to the very low frontal area per unit mass of freight. Aerodynamics of multiple trailer units can be improved by fairing the tractor unit and covering the gap between the units.

Buses usually come with many of the aerodynamic features (air dams, side skirts and boat tailing) identified as useful in the CADDET demonstration project reported above. Some go further and have rear wheel well covers. Attention to door and window details, mirror fairing and exterior light fittings during refinement of body designs could improve aerodynamics further.

7.3 Rail Transport

Rail transport in New Zealand has historically been operated as a state monopoly. Over the last decade, the government's corporatisation and privatisation policies have completely changed the organisation of New Zealand Rail, which is now privately owned. After many years of heavy losses, the organisation now makes an operating profit and in doing so has considerably reduced its staffing and dispensed with some loss-making services.

Inter-urban passenger transport has experienced the greatest reduction, with a number of branch line closures. However, this process now seems to have stabilised, and there have been one or two new tourist-oriented passenger services started up over the past three years. Suburban rail services continue in Wellington and Auckland, the former using electric multiple units and the latter relying on diesel-electric railcars.

Long distance bulk freight is the market in which rail has traditionally been the most competitive and this continues to be the main focus of its operations.

Energy Use Trends

In 1992, rail transport consumed 48 million litres of diesel oil and 39.5 GWh of electrical energy, in total 2.0 PJ or 1.5% of transport energy consumption within New Zealand (provisional figures for 1994 indicate an increase to 2.2 PJ). Total energy use in suburban rail passenger operations (Auckland and Wellington) has fallen by about 15% since 1985, which is in line with a decline in rail passenger journeys (especially in Wellington). Over the same period, the total energy consumption in rail freight has declined even further, by 36%. This reduction is partly attributable to improved energy efficiency and partly to a decline in freight tonne-km (perhaps by 20%). Between 1985 and 1994, the energy efficiency of freight improved from 0.85 MJ/tonne-km to 0.77 MJ/tonne-km, or by 9%. Over the same period, no change was evident in the average energy efficiency of passenger rail (1.24 MJ/p-km).

Future Outlook

The corporate restructuring and privatisation of New Zealand Rail, together with its improved financial performance, should secure its future. It is possible that some further trimming of unprofitable services will occur, but these may be balanced by expanded business and there has been a slight increase in freight tonnage over the latest reported financial year, the first such increase since the mid-1970s. However, it appears unlikely that the size and profitability of operations will permit large capital investments of the order of the North Island Main Trunk electrification project.

Overall, the most likely scenario is a continuation of the present pattern of business with incremental changes as rolling stock is replaced, innovation through targeting specific areas of new business and through intermodal efficiency improvements (particularly combined rail and road haulage).

There is little opportunity for the introduction of the more prominent rail technology employed overseas, such as high speed rail passenger services (e.g. British HST, French TGV or Japanese shinkansen). The narrow gauge and low passenger density in New Zealand precludes such capital investment. Also ruled out are urban metro rail systems, which involve unaffordable capital investment and rely on high corridor densities. However, light rail/street tram has many advocates and has the merits of catering for lower passenger densities and requiring moderate capital investment. Data on the energy efficiency of light rail, from overseas experience, is presented in Chapter 6.

Opportunities for Energy Efficiency

Electrification of the main trunk line through the central North Island allowed substitution of electric locomotives equipped with regenerative braking for the diesel-electric locomotives that serve the remainder of the system. Harris et al. (1993) report that this track section accounted for 20 million litres of diesel per year (over 200 GWh equivalent), which has been substituted with 25 GWh/year of electrical energy (data from New Zealand Rail) equivalent to around 80 GWh of primary energy (natural gas and coal). If these figures are correct, then they indicate a significant energy efficiency gain, possibly due to the regenerative braking and removal of losses in the diesel-to-electricity-to-motive-power conversion.

New Zealand Rail advises that it plans to use electric locomotives on the long distance passenger services over the central North Island section, further substituting diesel with electrical energy (Bone, 1994). It is unlikely that there will be significant further investment in electrification of additional rail lines in view of the very high capital cost involved.

The fleet of DX diesel-electric locomotives that serves the remainder of the rail system are likely to remain in service for the foreseeable future. Significant change in track alignment is unlikely, and a maximum train weight of 1000 tonnes will continue to be the upper limit. Therefore, energy efficiency of long distance rail freight will not undergo much change.

For the suburban passenger services, the Wellington multiple units were renewed in the early 1980s, but new diesel-electric multiple units were introduced to Auckland in July 1993. The latter were more energy efficient than their predecessors; the diesel consumption on the Auckland service has decreased by almost half (from 1.3 M litres in 1993 to 0.7 M litres in 1994).

7.4 Sea Transport

The Coastal and Inshore Fleet

Altogether, coastal and inshore vessels engaged in or supporting transport operations consumed an estimated 2.5 PJ of energy in 1992, or 1.8% of domestic transport fuel. Provisional figures for 1994 indicate a rise to 2.74 PJ. Nonetheless, between 1990 and 1994, fuel consumption fell by 5%. Freight data limitations make it difficult to estimate the energy efficiency of coastal shipping (MJ/tonne-km). Transport analysts consider there has been little change in the energy efficiency despite a gradual increase in vessel size (Bone, 1994).

New Zealand coastal shipping services are provided by a relatively small fleet of vessels, comprising three general/RoRo cargo vessels, three dry bulk carriers (cement) and four liquid bulk carriers (oil products and LPG). As most of the larger New Zealand vessels are purchased secondhand, any fuel efficiency improvements will be by retrofitting rather than in the original design.

In addition to the main coastal vessels, there are three all-year-round inter-island ferries, various inshore vessels, harbour and gulf ferries, harbour workboats, tug and barge operations and small tourist vessels. Not included in the transport sector, but a significant fuel user, is the off-shore fishing fleet.

About 100 coastal and inshore vessels of 100 GRT or more account for almost 100,000 tonnes of annual fuel consumption. Against this, a further 2500 smaller craft of under 100 GRT but exceeding 24 m in length are estimated to consume over 150,000 tonnes (no doubt including a high proportion of inshore fishing vessels), while an estimated 10,000 diesel-powered boats under 24 metres consume a further 10,000 tonnes, and 60,000 petrol-fuelled outboards a further 20,000 tonnes (although very little data exists to quantify these last two categories).

This make-up of the shipping fleet indicates that:

- Energy efficiency improvement for transport tasks lies with the replacement or re-equipping decisions for a handful of vessels. Replacement occurs quite infrequently and fuel efficiency will only be one factor considered. As fuel prices have been falling in real terms, there is little pressure to either re-engine or make other capital intensive changes to improve fuel efficiency.

- Efficiency improvements in the more numerous smaller vessels, which are generally not used for transport purposes (rather for fishing, tourism and leisure), stand to have a greater overall impact.

Overseas Shipping

Bone et al. (1993) estimated that while some 200,000 tonnes of fuel is bunkered in New Zealand by overseas vessels, this represents only a small fraction of the fuel consumed in delivering New Zealand exports to market and in transporting imports. A true allocation is difficult to determine because cargo is carried for several countries on overseas vessels at any one time, but around 1 million tonnes is estimated as the fuel used in transporting New Zealand's exports each year.

New Zealand relies heavily on overseas trade, so the cost efficiency of international shipping services is of obvious concern. In recent years, the government has greatly improved efficiency and reduced the costs of port handling through its deregulation and corporatisation reforms. However, government has limited influence over the international shipping sector, which is largely controlled by overseas shipping companies. Only 13 foreign-going vessels are under New Zealand ownership and of these, only six are New Zealand registered. This can be contrasted with the 70 or so vessels engaged in liner services to New Zealand, and a much larger number of charter vessels that call at New Zealand ports to no fixed schedule.

In overseas shipping, future demand for services will be governed by growth in the New Zealand economy, the volume of import and export trade and, to a minor extent, the competition from air freight. Over the last decade, export cargo tonnage has increased by around 5% a year while import tonnage has increased by 2% a year. The imbalance in growth has led to a situation where export volumes exceed import volumes by 40%, creating a directional imbalance in flows compared with the early 1980s, when import and export volumes were roughly equal.

International shipping is currently experiencing significant change. Most of the world's fleet is aging and due for replacement. The trend is now towards very large vessels, which have the potential for improved energy efficiency. Higher energy efficiency, lower crew numbers and other economies of scale make large vessels economical to run, providing load factors are high and turnaround times minimised. A problem is that very large vessels (over 100,000 tonnes) cannot use most New Zealand ports. On the other hand, their operators would not want them to visit many ports to obtain a full load anyway.

It is quite likely that the hub and spoke system will become more widespread to accommodate large vessels. Under this system, smaller coastal or cross-ocean vessels concentrate loads from small ports along spoke routes to a major hub port. Large vessels move cargo from hub to hub. Distribution then takes place along spokes. As economics favours the hub-to-hub shipment, it would be in New Zealand's interest to have at least one hub port developed as part of future reorganisation of shipping in the Oceania region

Outlook for New Zealand Sea Transport

Coastal shipping tonnages experienced a substantial decline from the mid-1970s to the mid-1980s that was caused by competition from road and rail and by resistance to change from within the maritime sector. Industrial reform and corporatisation of the country's ports greatly improved the efficiency of coastal shipping, which was in danger of collapse, and cargo tonnages have recovered. However, there will continue to be strong competition from rail, which is the main alternative for the carriage of long distance freight.

The most significant change for the coastal shipping industry is the permitting of cabotage, the carriage of coastal cargos by overseas shipping calling at New Zealand ports. This proposal was nearly passed into law in 1993, but was forestalled by an election. It was eventually passed as part of the Maritime Transport Act 1994 and came into force on 1 February 1995. Energy efficiency implications derive from the reality that overseas vessels typically bring cargos into Auckland and take out exports from ports further south. Making use of the cargo space on the trip from Auckland to southern export ports could save fuel.

Opportunities for Energy Efficiency

Opportunities for improved fuel efficiency lie in:

- better thermal efficiency in marine propulsion units;

- improved efficiency of ships propellers;
- hydraulic drag reduction;
- using larger vessels;
- reducing vessel speed;
- improving load factors; and
- new propulsion systems.

Marine Propulsion Units

Over the past two decades, marine engines have been designed to burn the heavier grades of fuel oil, solely because of cost considerations (compare US$120/tonne for 180 centistoke fuel oil compared with US$240/tonne for Marine Diesel Oil). The heaviest grades now used in shipping (380 centistoke) are not available in New Zealand, but this is not a constraint as most fuels are bunkered overseas at the cheapest supply point on the route.

Water emulsification in marine diesel fuels has been researched at Newcastle University and trialled by at least one container shipping line with some success. The water addition produces steam in the cylinder, raising the pressure and aiding fuel vaporisation with efficiency gains. Cleaner fuel injectors are a secondary benefit. Although the benefits are quite well proven, there is probably more scope for application of this technology.

As heavier grade fuels oils have been introduced, marine diesel engines have been designed to operate at much lower speeds, down to 60 rpm in some cases.

Propeller Design and Maintenance

Advances are being made in the design of ship propellers. The fewer blades, the more efficient the transfer of energy from the shaft to useful work, subject to dynamic stability. Two-bladed propellers tend to be unstable and three-bladed propellers are the optimum. Twin-screw propulsion, previously required because of torque limitations in prop shaft design, is giving way to single screw, with large diameter, low-speed propellers. Computer-aided design of ships propellers is likely to bring further efficiency gains.

Improved maintenance of propellers in itself brings efficiency benefits by removing fouling and correcting pitting. A wire brushing alone can give a 3% improvement in fuel economy.

The efficiency of propellers can also be improved by retrofitting flow correcting devices. During operation, a ship's screw propeller generates a hub and tip vortex which waste energy. Many studies have been carried out on reducing tip vortex, but hub vortex is often ignored. New propeller boss caps with fins (PBCF) eliminate the hub vortex by controlling flow around the propeller boss (the boss is like the nose cone of an aeroplane propeller, except that it faces the stern of the vessel — it streamlines flow that has passed near the centre of the propeller). The PBCF has a small set of fins that act like a second propeller. Tests on vessels from 500 to 200,000 gross tonnes show the device can provide efficiency gains of between 2% and 8% (CADDET, 1991). Payback periods for the retrofit are typically less than two years.

Hydraulic Drag Reduction

Hull shape and roughness influence hydraulic drag. Hull shape is largely built into the vessel during construction, although some retrofit improvements can be made. Most of the improvements in hydraulic design were made during the 1970s and 1980s, when the incentive to do so was strong. However, there are still probably gains to be made in hull shape. Deep-hulled vessels tend to be more efficient, although this must be subject to draught constraints of the principal waterways and harbours.

The smoothness of the hull can deteriorate with time from corrosion and fouling. Surface roughness leads to earlier breakdown of laminar flow as the vessel speed increases. When first preparing the hull for painting or during a major refit, fine shot-blasting provides a base for a smooth surface, which can give 10% reduced drag over a less carefully prepared surface. Self-polishing paints also provide improved smoothness and lower hydrodynamic resistance than conventional paints. Older New Zealand vessels have probably not been shotblasted back to bare metal and their drag resistance could no doubt be improved, but the cost of doing so may make this uneconomic.

Ship Size

In general, installed engine power increases with the carrying capacity of the vessel. An analysis of liner services on the New Zealand trade shows that installed kW is proportional to 0.55 x DWT tonnage. Where installed power falls above this linear relationship, the vessels are generally on faster services, typically RoRo, which competes on fast turnaround time, while vessels below this regression line are commonly the bulk carriers, where steaming time is not at such a premium.

Potential steaming speed increases with the size of the vessel. The fuel consumption per tonne-nautical mile is lower for cargo vessels, in part because the steaming speed is higher and energy overheads are lower.

Steaming Speed

As the speed of a vessel increases, the power requirement increases by the third power. Consequently, the easiest way to increase fuel efficiency in shipping operations is to cruise at lower speeds. This was the initial response when the energy crisis developed in the mid-1970s. There is a commercial trade-off to be made between speed, costs and the competitiveness of service. While the value of speed is not as high as used to be the case in the days of the tea clippers, for liner trades the number of vessels required on the service, the service frequency provided and the transit time are interrelated considerations in any company's marketing strategy.

Improved Load Factors

As with any transport mode, a high load factor means greater fuel efficiency. Provided that vigorous free competition exists, individual ship operators will strive to achieve the maximum load factor on their services consistent with their other commercial objectives, primarily to be profitable. This may not, and probably will not, be the highest load factor that could be achieved if all shipping services were coordinated to optimise load factor (or, for that matter, to optimise fuel demand).

The directional imbalance in cargo volumes referred to above implies an overall reduction in load factors for overseas trading vessels and, if the New Zealand economy prospers, this is bound to continue as the value of the bulk of exports is considerably lower than for imports. In practice, load factors are constrained by cargo form — a number of the major bulk commodities involve specialist vessels with no return load.

New Zealand no longer attempts to influence the shipping services market through direct participation in the industry (as in the days of the New Zealand Shipping Corporation). There are no institutional or technical barriers to the introduction of new technology or other sources of improved energy efficiency except those that affect the world shipping market as a whole and the particular trade patterns within the South Pacific. An exception to this is trans-Tasman trade where, as pointed out by Harris et al. (1993), the "maritime accord" between Australia and New Zealand effectively limits competition on this route to vessels of the two nations and probably leads to lower load factors on services into New Zealand than would otherwise be the case.

New Propulsion Systems

Large modern vessels and most smaller vessels are driven by screw propellers. Jet units are used on small boats and vessels to several hundred tonnes. Sail power is used on yachts and is still used on small freight-carrying ships and fishing craft, even modern versions. Experiments are under way to extend the range of propulsion options available. One of these experiments, of particular interest because (like windpower) it is based on a renewable energy resource, is described here. The technology under development has the potential to significantly reduce the energy consumption of vessels across a wide size range.

Ocean waves contain vast amounts of energy, about ten times more concentrated than wind and more constant. The average wave power around New Zealand is probably 30 kW per metre in most places (Eden Resources, 1993). Some places within territorial waters have 50 kW/m power content or more. A 70 metre long offshore vessel with waves abeam could be passed by 3500 kW. Such a vessel only needs a shaft power of around 1000 kW to maintain a speed of 12 knots. Even if the ship was at a different orientation to the waves there would be enough wave power to propel it.

Experiments in Norway are based around the use of foils or underwater wings to harness this energy (CADDET, 1995). Figure 7.3 shows the basic geometry and mechanics of such a foil. Essentially, the wave-induced vertical movement of the vessel and foil relative to the water is converted into forward thrust.

The leading edge of the wing is mounted on a pivot, which is connected to a support structure. The wing is also connected to its support structure by an "elastic" hydraulic, pneumatic or spring device that tries to keep the wing in a neutral horizontal position. When the supporting structure is moved downwards the trailing edge of the wing deflects upwards thus exerting a forward thrust on the structure. Similarly, when the structure is moved upwards, a forward structure is again produced.

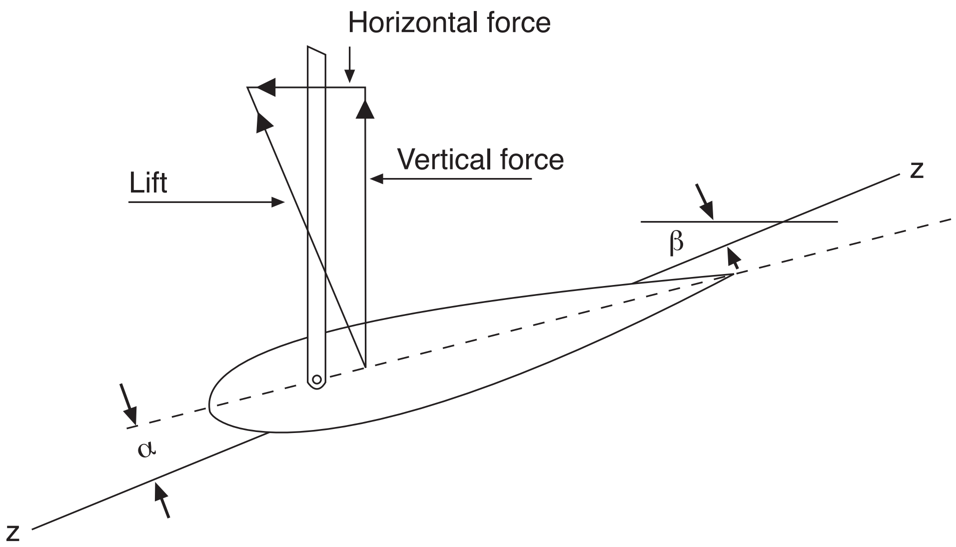


Figure 7.3: Working principle of the foil propeller

The wing produces drag but this is more than compensated for by the forward thrust. Foils do not have to be large (several square metres) to provide valuable assistance to propulsion. They can be raised or otherwise stowed when the boat is manoeuvring in tight corners, berthing etc.

Tests on a 20 metre long 180 tonne boat with two 1.5 metre foils indicated that the foils provided 12% to 22% of the propulsion needed in 3 metre waves. Computer analysis of the use of foils shows fuel savings as being proportional to the foil area. With a foil area of only 3% of the waterline area, a 40 mere ship would save 64% of fuel at 8 knots, while a 180 metre ship would save 35% at a speed of 17 knots. Clearly, this technology is worth further development.

7.5 Air Transport

Energy Use in Air Transport

Data on the total energy consumption and energy efficiency of air freight services is not readily available. The energy demand of freight services are difficult to separate out from passenger services.

Energy efficiency on domestic passenger services has increased from 3.3 MJ/seat-km in 1974 to 2.5 MJ/seat-km in 1990, an improvement of nearly 25% over 16 years. In terms of energy efficiency per passenger-km, the improvement has been much less dramatic as the efficiency gained through improved airframe and aero-engine design has been offset by lower load factors since the introduction of competition on the main domestic routes. From available data, it appears that over 30% improvement in energy efficiency was achieved between 1975 and 1982 on the domestic services, partly through technical improvements in aircraft and partly from higher load factors. However, by 1990 only 10% of this gain remained. Between 1985 and 1990, the specific energy demand of domestic air travel rose from 3.26 MJ/p-km to 4.29 MJ/p-km (EECA, 1995). Reliable data is not available for more recent years.

Future Outlook

Air transport is likely to continue to experience strong growth, particularly on international sectors as the real cost of air travel is expected to fall further and as tourism to New Zealand continues to grow. All of the main gateway airports have plans for considerable expansion over the short- to medium-term.

A feature of air transport that does not equate with fuel efficiency is the strong growth in helicopter operations, for tourism and shuttle transport as well as for the traditional roles of heavy aerial lift, rescue and other aerial work.

Opportunities for Energy Efficiency

Further scope exists for substantial improvement in fuel use per seat kilometre through improved aero-engine design, the employment of modern lightweight materials and highly sophisticated engineering design of airframes. However, the cost of developing a new commercial transport aircraft is such that it can only be contemplated by a handful of companies and often relies heavily on government sponsorship and international co-operation. Consequently, New Zealand is not in a position to influence the technology at this level, even though it has had some success at a more modest scale.

Air New Zealand has been introducing new and more efficient aircraft to its international fleet as they come on to the market. As fuel comprises a reasonably large share of air transport operating costs, it is obviously in this company's interests to do this, and the extended range available from new generation aircraft is of particular advantage for the long sector lengths characteristic of Air New Zealand's overseas operations. Therefore, there is little untapped opportunity to improve fuel efficiency by aircraft replacement. The same may not be true of the domestic fleet. Air New Zealand has aging 737s compared with the modern aircraft of its competitor, Ansett New Zealand.

Load factor on the domestic routes is the obvious area where there is considerable scope for improved fuel efficiency as the advantages to the customer of domestic air services competition have, to some extent, been obtained at the expense of fuel efficiency. There is scope for a 20% gain if the load factors of the mid-1980s were to be regained. However, for the present at least, it is highly unlikely that the travelling public would wish to give away the very evident consumer benefits of competition for the sake of fuel economy alone. Harris et al. (1993) devotes some discussion to the possibility of introducing some form of minimum load factor requirement on the industry, but the practicality and political acceptability of such a move would require careful consideration. It is quite possible that the present low load factors will not be sustainable and will lead to a reorganisation within the industry in the medium term. This could well bring with it higher load factors.

The same report drew attention to inefficiencies introduced through air traffic congestion, particularly at Wellington, noting that improved air traffic guidance systems (a microwave landing system or global positioning by satellite combined with enhanced vision technology) may relieve this situation.

7.6 Conclusions

Air freight is markedly more energy intensive than the other modes (road, rail and sea) but often satisfies special needs, such as speed of delivery, that make comparisons with the other modes inappropriate.

There is considerable overlap between the energy efficiencies of road, rail and sea modes. None of these modes can be said to be universally superior to the other two. Comparisons have to be made with care and on a case-by-case basis. The full transport system needs to be considered from origin to destination, including all mode changes. Sea and rail freight have been deregulated and are now on a fully commercial footing. Road freight has been deregulated and studies are underway to check that all road users are paying the full costs of their activities.

A prerequisite for greater consideration of energy efficiency by the transport industry is to have all the modes competing on the same basis. Fuel costs are a fairly important component of overall costs, and in a highly competitive environment, freight operators will need to look carefully at energy efficiency opportunities. Each mode needs to be made as efficient as possible, and this chapter has identified various means to achieve this goal. Furthermore, rather than treating modes as alternatives, adopting an integrated approach is suggested. For example, it may be more beneficial from a commercial and energy efficiency perspective to look at integrating road, rail and coastal shipping services. This can occur in a competitive environment, but does require industry leadership.

Road freight efficiency can be improved by increasing load factors, increasing the ratio of payload to gross vehicle weight and reducing vehicle losses, especially aerodynamic drag. The means to achieve these results include freight brokerage systems; greater use of lightweight materials; possibly the creation of special heavy transport routes to allow an increase in maximum GVW; and aerodynamic streamlining of truck and trailer units. The benefits of the latter are well documented but may need to be better disseminated amongst the trucking industry.

There have been significant improvements in the energy efficiency of rail freight since 1985. The outlook, however, for the next ten years or so is for little further change. This is because the closure of small branch lines is complete, the benefits of electrifying the main trunk line have been realised, the existing fleet of DX diesel electric locomotives is likely to remain in service and the difficult New Zealand terrain precludes major changes to maximum train size and track alignment.

Total energy use by coastal shipping appears to have fallen since 1990, but a reliable trend in energy efficiency is not available. It is difficult to predict future trends as vessel or engine replacement occurs infrequently and fuel efficiency is only one of several criteria for such investment decisions. Meanwhile, the efficiency of the vessels in service could be influenced by improving load factors and attention to hull and propeller maintenance and opportunities for retrofits, such as PBCFs. In the long term, new efficient propulsion systems such as the use of underwater foils to tap wave power may become commercially proven and widespread.

Data on the energy consumption and energy efficiency of air freight services is not readily available. The energy demand of freight services are difficult to separate out from passenger services. The energy intensity of passenger air services (MJ/p-km) rose from 1985 to 1990. The advantages of competition between airlines may have been obtained at the expense of fuel efficiency. Improving load factor may be the best means of improving energy efficiency. This may come as a matter of course if the two main competitors merge or see mutual benefits in greater cooperation. Other potential means to improve energy efficiency include air traffic control improvements to reduce delays while waiting for clearance to land at airports.

Chapter 8
Public Policy Options

8.1 Introduction

Previous chapters have examined means for improving transport energy efficiency. This chapter discusses whether there is a role for public policy to facilitate these means, make changes occur more rapidly than they would otherwise, or overcome obstacles to the uptake of energy efficiency technologies.

The introduction to this chapter outlines the different ways public policy can alter behaviour and the variables, or areas, of the transport system that could be targeted for policy attention. There are many stakeholders in the transport sector. The main ones are noted and the need to understand their motivations and circumstances when developing policy is emphasised in the introduction. A list of potential policy measures, categorised by impact area and policy type, is provided. It is argued that dealing with vehicle efficiencies, driving skills and pricing issues should be priorities for policy investigation.

Section 8.2 outlines the current transport energy trends in New Zealand and then presents a case for why public policy is needed in this area. The section then goes on to outline the current status of policy development in this country.

Section 8.3 describes a range of selected car, driver and pricing-oriented policies mooted for New Zealand, or in use or under consideration overseas. The chapter ends with a commentary on public policy for transport energy use (Section 8.4).

Public Policy Categorisation

Public policy can affect individual, corporate and government agency behaviour in a variety of ways, such as through:

- mandating information and advice services;
- assisting with demonstration projects and R&D;
- providing education programmes to change attitudes;
- providing government leadership and role models;
- empowering local authorities and other public agencies;
- regulating for minimum performance standards;
- altering the market environment by changing tax and levy regimes; and
- ensuring prices match true costs and that there is fair competition.

Various policy instruments or measures can be developed that work through one or more of the above ways of affecting behaviour. Quite often, policy measures will be categorised according to the method they adopt to affect behaviour:

- economic measures — supply, pricing and demand relationships;
- regulatory measures — coercion, constraints on choice; and
- information — persuasion and facilitation.

In reality, it may be difficult to place a single measure exclusively in one of these categories. Quite often, the most successful policy initiatives consist of an integrated set of economic, regulatory and information measures.

Policy Stakeholders

Transport decisions, and consequently energy demand, are the result of a large number of private, corporate and government decisions. Some of these decisions may not have been taken with transport energy use in mind, but have impacted on this use nonetheless because the factors that determine transport energy demand are numerous and interrelated. An essential starting point for policy development in this area is an understanding of the stakeholders, the key players whose decisions can influence transport demand and how it will be satisfied.

Figure 8.1 shows the spheres of responsibility for road transport. Legislators and administrators at various levels of government can affect drivers and other transport system users, vehicle manufacturers and fuel suppliers. Some policies relate to the transport network (such as providing better roads), its operation (for example, policing speed limits) or the mode options it provides (extent of public transport).

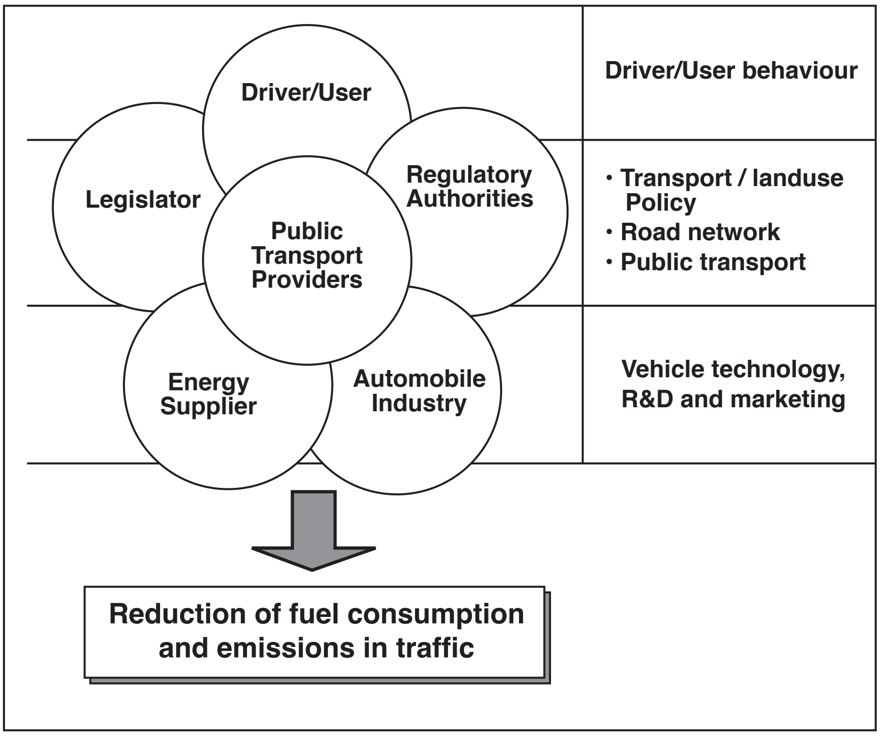


Figure 8.1: Road transport — spheres of responsibility

Policies can also focus on creating incentives for producers to make vehicles with advanced efficiency technologies and on encouraging consumers to buy more efficient vehicles — the so-called market push-and-pull approach.

A policy effect can be direct, such as through regulating minimum performance standards, or can rely on the marketplace responding to new information. This new information could be driver education on the consequences of fuel use and provision of vehicle fuel consumption data. Price is a very important piece of market information. Consumer demand for efficient vehicles or a willingness to improve driving performance could also be stimulated by increasing the cost of fuel.

In the design of policy instruments, it is important to understand the position and motivations of stakeholders and identify potential synergies between them. Raising the price of petrol to encourage the use of public transport, for example, may not be of much use if fuel bills still constitute only a small part of the overall cost of running a car or if resistance to using public transport translates into a high willingness to pay for private car use. Motor vehicle manufacturers are concerned with competition. They may not support fuel consumption data being made available if it will reflect badly on their products. On the other hand, there may be legitimate concern over whether the testing method treats all vehicles fairly.

Getting the fuel supply industry to support energy efficiency initiatives may be difficult because, at face value, it means loss of sales and potential profits. The task may be easier if the efficiency gains are to occur in an expanding market (so that fuel use will rise, but not as much as without the efficiency gains). In a competitive environment, fuel suppliers may be expected to offer energy efficiency advice to fleet managers to add value to their service. However, most fuel is not sold under fleet contracts.

The point is that to obtain fuel supplier support for energy efficiency initiatives, their position and underlying motives need to be appreciated. This is the same for all stakeholders, including legislators and administrators.

Policy Impact Areas and Measures

Policy measures can be designed to act in a certain manner (e.g. through information) on certain stakeholders (e.g. car drivers) to achieve change in a particular impact area. In the transport sector, the range of impact areas that could be addressed can be summarised as follows:

- growth in the vehicle numbers;
- growth in vehicle use — km/vehicle/year;
- unit emissions for existing vehicles;
- new vehicle mix — type, engine size and fuel;
- new and existing fleet performance;
- fuel mix — diesel, alternative fuels;
- modal split — public transport; and
- fuel efficiency — future improvements.

For each of these impact areas, a set of potential economic, regulatory or information type measures can be developed. Table 8.1 provides a fairly complete menu of policy measures from a recent International Energy Agency report (IEA, 1993). It should be noted that some measures, for example fuel taxes, could be used to impact on several areas. The classification system used in Table 8.1 is vehicle-oriented (the impact areas relate to different aspects of vehicles). Other policy classification systems have been proposed that focus on sets of measures, such as urban planning. This alternative approach is useful when packaging up sets of measures for consideration by different professional groups (e.g. town planners).

The choice of policy measure will usually be based on applying a range of considerations that includes cost-effectiveness, equity implications, the level of policing required, the likelihood of perverse effects, the degree of public funding support needed, the attitudes of stakeholders, etc. The need for a measure, and in fact any public policy, is usually predicated on analysis that indicates societal objectives would be better met with a change in the status quo than with the present situation and related future trends.

This chapter does not aim to set out a comprehensive case for public policy in the transport-energy use area, although it is suggested in Section 8.2 that in terms of at least one societal goal (climate change mitigation) something should be done. Similarly, the chapter does not aim to identify the best policy measures. It does, however, suggest that the major share of political, intellectual and other policy resources will need to go into the issue of cars and car driving. The reasons for this view are outlined below.

Priority Policy Impact Areas

Over the last 20 years, within the OECD (24 industrialised countries of North America, Europe, plus Japan, Australia and New Zealand):

- the car fleet has increased three-fold;

Area of Impact	Economic Measures	Regulatory Measures	Information
1. Fleet growth	- Annual fees for "right of access" to a vehicle - Vehicle purchase taxes - Fuel Taxes - Annual ownership taxes - Parking fees - Road use fees or kilometrage charges	- Annual sales quotas - Individual ownership limits (e.g. total number, no car without a parking space) - Closing some urban districts to cars - Limits on elective or professional travel - Limits on number of parking spaces - Increasing congestion by not improving infrastructure - Better infrastructure for bicycles, pedestrians - Expanded/improved public transport and lanes restricted to certain users	- Public information on mode cost comparison
2. Fleet mix	- Taxes and rebates on vehicle purchase determined by size, power or fuel consumption - Fuel taxes - Annual registration taxes determined by engine size - Manufacturer fiscal incentives for fuel efficiency, or fees for non-compliance with standards	- Minimum fuel efficiency standards (e.g. CAFE) - Maximum emissions standards - Maximum power/weight ratios - Civil penalties for manufacturer non-compliance with standards or requirements - Annual sales quotas (by vehicle size)	- Public advertising promoting clean, fuel efficient small cars
3. Unit emissions	- Fiscal incentives for successful vehicle inspection or non-compliance fees - Fiscal incentives to retire old vehicles or non-compliance fees - Fiscal incentives for vehicle maintenance or non-compliance fees - Fiscal incentives or non-compliance fees for driver training, especially professional drivers - Subsidies for R&D focused on vehicle performance - Annual registration taxes determined by engine size/fuel efficiency - Manufacturer fiscal incentives for performance standards (e.g. durability of fuel efficiency) or non-compliance fees	- Vehicle performance standards (e.g. durability of fuel efficiency) - Maximum power/weight ratio - Mandatory driver training, especially for professional drivers - Mandatory retirement of old vehicles - Mandatory vehicle inspection using fuel efficiency criteria - Mandatory regular vehicle maintenance - Penalties for non-compliance with standards or requirements - Speed limits (enforced)	- Automotive press coverage of vehicle performance and operating costs - Use of vehicle inspections to inform consumers about driving behaviour and vehicle maintenance - Public campaigns associating efficient driving with safe driving - Public information on efficient driving and vehicle maintenance

Table 8.1: Policy measures to influence passenger transport supply and demand and their areas of impact (IEA, 1993)

Area of Impact	Economic Measures	Regulatory Measures	Information
4. Vehicle use	- Fuel taxes - Insurance rates by annual kilometrage - Parking fees - Road use fees or kilometrage charges	- Car use restrictions (e.g. odd/even plate numbers) - Closing some urban districts to cars - Limits on elective or professional travel - Limits on numbers of parking spaces - Premium parking for high occupancy - Increasing congestion by not improving infrastructure - Speed limits (enforced) - Expanded/improved public transport and lanes restricted to certain users - Better infrastructure for bicycles, pedestrians)	- Public information on efficient driving and route planning - Public information on alternatives to mobility (e.g. telecommunications)
5. Fuel mix	- Fuel taxes differentiated by fuel - Taxes for high emitters/rebates for low emitters at purchase or in annual car registration fees - Fiscal incentives for development of alternative fuel distribution networks - Subsidies for R & D on alternative fuels - Rebates for conversion to dual-fuel vehicles - Low rental rates for alternative fuel equipment - Manufacturer fiscal incentives for fuel quality standards, emission standards, performance standards; or non-compliance fees	- Fuel quality standards - Emission standards - Performance standards - Penalites for non-compliance with standards or requirements	- Automotive press coverage of vehicle performance and operating costs - Use of vehicle inspections to inform drivers about alternative fuels - Education and information programmes

Table 8.1: (continued) — Policy measures to influence passenger transport supply and demand and their areas of impact

Area of Impact	Economic Measures	Regulatory Measures	Information
6. Modal split	- Vehicle purchase taxes - Fuel taxes - Annual licensing taxes - Annual ownership taxes - Parking fees - Road use fees of kilometrage charges - Subsidies for public transit, trains	- Car use restrictions (e.g. odd/even plates) - Ownership limits - Closing some urban district to cars - Limits on elective/professional travel - Limits on numbers of parking spaces - Expanded-improved public transport and lanes restricted to certain users - Park-and-ride facilities - Better infrastructure for bicycles, pedestrians - Subsidies for taking alternative transport to work	- Public campaign promoting alternative transport modes - Public campaign promoting alternatives to mobility (e.g. telecommunications) - Cost comparisons for cars and public transport
7. Fuel efficiency technology	- Fuel taxes - Taxes for high emitters/rebates for low emitters at purchase or in annual car registration fees - Grants, loans, subsidies for fuel-efficient vehicles - Subsidies for R & D on fuel efficiency - Manufacturer fiscal incentives for fuel efficiency standards, emissions standards, power/weight ratio limits; or non-compliance fees - Tradeable fuel economy credits	- Minimum fuel efficiency standards (CAFE or some other concept) - Maximum emissions standards - Maximum power to eight ratios - Penalties for non-compliance with standards or requirements	- Annual publication promoting new car fuel efficiency technology
8. Fleet emissions abatement	- Tax differentials favouring abatement technology on new cars - Taxes for high emitters/rebates for low emitters at purchase or in annual car registration fees - Fiscal incentives for retiring old cars - Rebates for conversion to dual-fuel vehicles - Manufacturer fiscal incentives for fuel efficiency standards, emissions standards, power/weight ratio limits technology prescription; or non-compliance fees - Fiscal incentives or non-compliance fees for vehicle inspection	- Maximum emissions standards - Fuel quality standards - Maximum power to weight ratios - Technology prescription (e.g. catalytic converter) - Mandatory retirement of old vehicles - Mandatory vehicle inspection using emission technology and/or performance criteria - Civil penalties for non-compliance with standards or mandatory requirements	- Annual publication of new car emissions levels by fuel and vehicle type - Driver awareness programmes

Table 8.1: (continued) — Policy measures to influence passenger transport supply and demand and their areas of impact

- passenger car travel (person-km) has doubled, while passenger rail travel has only increased by 20%;
- road freight has doubled, while rail freight traffic has decreased by 10%; and
- air traffic has increased four-fold.

The New Zealand experience over the last five years, outlined at the start of the next section, indicates that similar trends are continuing in this country unabated. There has been a powerful shift to the road network as the principal means of transport and motor cars, in particular, as the dominant passenger transport mode. Greater access to motor cars and an improvement in road quality has shaped attitudes to personal mobility and the increased freedom of choice over destination, route and journey scheduling is highly valued. Passenger car travel has increased dramatically. Both in New Zealand and other OECD countries, urban development and transport infrastructure investments have reinforced this growth.

Some commentators interpret the trend as a failure of planning and proper public transport policy. In Chapter 1 it was argued that for New Zealand, with its special geographic features, embracing road transport may have been a cost-effective strategy that has only recently reached the point of diminishing returns, and then only in some areas. Whatever the merits of past decisions, New Zealand and many other OECD countries are at the point where car travel is so dominant that radical changes in public transport use would have little effect on overall sector energy use. The type of public transport changes required to have a marked effect in the medium term (say a 5% reduction in fuel use overall) would require massive investment to provide new services, and steps to curtail car use would certainly be required as well.

There will be situations where investment in new public transport services is now economic. In many cases, though, heavy subsidies would be needed to rapidly expand services to the level needed to have a marked effect on fuel use. Quite often, it would be hard to justify these subsidies, even if an optimistic view of public transport benefits was adopted and a high price was placed on the externalities of car travel.

Steps to curtail car use, such as by prohibiting access by other than public transport, are fraught with difficulties. Urban development, land and property values, and landuses are to a large degree predicated on a high level of car access. This creates political resistance to restricting access. If cars are constrained from using one area, then there is a real likelihood that time-discretionary travel (shopping, recreation etc.) will go to a nearby, less restricted area. This may mean little change in energy use, but marked impacts on retailers and other service providers. A comprehensive cross-boundary approach to area restrictions would be needed to avoid distortions. It is little wonder that many commentators who advocate policies to curb vehicle use, favour increasing the price of fuel or other measures that retain freedom of choice.

Increasingly, the focus of overseas policy is turning to ways to get more efficient vehicles and better driving habits, or ways to use the price mechanism to have people question their car travel demand (the latter could have a spin-off for public transport use). Some commentators see such a policy focus as reinforcing the automobile culture and amplifying the problem at the expense of down-playing alternative transportation modes that might be a better incremental solution. This is a valid point, especially where the debate is over new public investment decisions — new motorways versus light rail development, for example. As noted below, other policy options should not be neglected. It should be appreciated, though, that cars are not only the problem, but *are part of the solution*, in that there is enormous scope to dramatically improve their energy efficiency, and (in New Zealand at least) to eventually fuel them from sustainable energy systems.

The outline of New Zealand policy development, in the next section, indicates that a car efficiency/driver performance/pricing approach is the main focus in this country. Section 8.3 provides an outline of a range of car oriented policies that have either been mooted for New Zealand or taken seriously overseas.

While there is a good case for trying to improve transport energy efficiency by working directly on car travel, issues such as improving urban form, encouraging public transport use, cycling and walking should not be neglected. Table 8.1 contains many policy measures that aim to deal with these issues. Some of these will be applicable to New Zealand and their introduction should be considered. It is important, though, to realise the limited applicability of some policy measures in a political and social climate that favours car use, freedom of choice, etc. It is also important to appreciate the limited short- to medium-term potential of policy measures on public transport and urban form to reduce fuel use. An appropriate and realistic goal for policies covering these matters is to halt the downward or adverse trends and create a base for future growth. In the long run, our cities must move onto a more sustainable footing. Sustainable cities will probably rely on a good integration of private and public transport modes. In the end, it is not be a case of one or the other, but a mix that meets the needs of people and the environment.

8.2 New Zealand Situation

This section outlines the current trends in New Zealand transport energy use and explains why some public policy action is needed. It then looks at the policy development work and transport energy use roles of different government agencies.

Trends and Policy Imperative

The major transport characteristics and trends for last ten years are:

- Cars/light commercials (60% of domestic transport energy use):
  - — ownership rate increasing;
  - — engine size increasing;
  - — kilometres travelled per car class is increasing;
  - — reducing load factor (i.e. lower occupancy rate);
  - — energy efficiency of technology employed is improving;
  - — preference for energy consuming options (e.g. airconditioning); and
  - — average age of cars remains constant.
- Heavy road freight (20% of domestic transport energy used):
  - — increasing road freight (possibly displacing rail);
  - — energy efficiency increasing (e.g. greater payloads and load factors);
  - — numbers of trucks decreased from a peak in 1983/84;
  - — increasing kilometres travelled per truck; and
  - — increasing size of trucks.
- Air (10% of domestic transport energy use):
  - — an historical trend towards improving aeroplane efficiencies (stated in MJ/available seat km) has been reversed since 1988 when competition caused load factors to drop on domestic routes.
- Coastal shipping (5% of domestic transport energy use):
  - — energy efficiency has been improving over the last ten years; and
  - — tonnage has been increasing over the last ten years.
- Rail (under 5% of domestic transport energy use):
  - — freight tonnage has decreased; and
  - — energy efficiency is improving.
- Public transport:
  - — declining public transport usage, from an already small base;

— bus size increasing (better energy efficiency when fully loaded); and

— rail passenger journey numbers are continuing a ten year decline.

- Fuels:

— decreasing LPG/CNG fuel use (from a low base of 4% of domestic transport energy use); and

— increasing diesel use by increasing numbers of cars and light commercials (although absolute tonnage is low in comparison to heavy trucks).

Even though New Zealand's population is not growing, energy demand for private motor transport is increasing while public transport usage is generally declining. In the last few years there has been localised improvements in public transport patronage (in Auckland for example) but the dominance of car travel remains.

Transport contributes over 40% of New Zealand's fossil fuel carbon dioxide emissions. Around 80% of the country's transport fuel is used by on-road motor vehicles. The key factor is that over 50% of road transport fuel is used by motor cars, and around 75% or more of this is for private travel.

The balance of long-term trends for motor cars favours a growing national transport fuel demand by this sector. The average car fleet fuel efficiency is rising and there is a slow shift to the use of diesel engines, but the energy saving potential of these factors is being offset by other trends. Public passenger transport patronage and car occupancy levels are falling. The number of vehicles overall, and per capita, and annual utilisation (kilometres per year) are rising. While there appears to have been improvements in the fuel efficiency of road freight, the growth in the economy suggests that fuel use in this sector will rise.

The net result of these trends is an expected increase in transport consumer energy demand of over 13% from around 165 PJ in 1990 to about 190 PJ in the year 2000. Carbon dioxide emissions from oil product consumption (mainly for transport) is expected to rise by 15% over the same period. The overall increase in emissions from all economic sectors is expected to be 18% to 20%.

There are financial incentives to improve the energy efficiency of commercial goods movement and public transport. With current petrol and diesel prices, private vehicle purchasing decisions, and choices over the frequency and extent of car use are not, however, strongly influenced by energy efficiency considerations. As pointed out in Chapter 1, an important social objective that has emerged over the last five years is the need to limit carbon dioxide emissions in order to reduce the risk of global warming. This social objective is likely to be a major rationale for future public policies to encourage greater transport energy efficiency, especially those targeted at private motorists.

Linking New Zealand's obligations under the Framework Convention on Climate Change (FCCC) with current trends in transport makes a *prima facie* case for policy action.

The government's basic strategy to deal with rising emissions (in terms of the FCCC obligation to stabilize emissions by year 2000 at 1990 levels) is to have new forest plantings offset 80% of the increase. The remaining 20% will be dealt with by way of emission reductions — steps will need to be taken to have the total emissions from all sectors 3.5% to 4% lower than they would otherwise have been in the year 2000. These steps include a mixture of existing policies — regional petrol taxes are quoted as part of the government's Carbon Dioxide Reduction Action Programme — and new initiatives, such as voluntary agreements with industry.

If transport is expected to achieve a pro rata reduction the same as, for example, the industrial sector, then emissions would need to be around 3% lower than otherwise by the year 2000 (or only 12% more than in 1990 as against the expected growth of 15%). While not a large target, a reduction runs against the trends. The existing policies for the transport sector are not likely to achieve this level of reduction. More will be needed.

Current Policies and Future Development

New Zealand's first report to the international community (Environment, 1994) on how it is dealing with its FCCC obligations cites four measures that have been adopted and are considered likely to reduce transport sector carbon dioxide emissions:

- Regional land transport strategies — introduced in 1992, these strategies are required to take environmental issues into account. Research is underway on how to deal with CO_2 emissions in the strategy development process.
- Road funding decisions — Transit New Zealand is developing procedures for incorporating CO_2 emissions into its cost benefit analysis for road network projects.
- Regional petrol taxes — a regional petrol tax to fund part of the cost of public transport was introduced in 1992 (this was largely a funding source change rather than an increase in public financing of public transport). While originally a temporary measure, the mandate for regional petrol taxes has been extended to January 1996.
- Speed limit enforcement — speed cameras were introduced in the first half of 1994 with a view to reducing the road toll through lower vehicle speeds.

Except for speed limit enforcement, the above policy measures are fairly characterised as having an indirect, medium- to long-term, and uncertain, impact on transport energy efficiency. They are unlikely to have any material impact on fuel use over five years, but may have some effect over ten years or more.

Work is underway to further refine or develop the above policy measures. Additional policy measures are also under consideration by government agencies. The work status of public policies that might impact on transport energy efficiency is outlined below under the heading of the respective lead agency.

Ministry of Transport

Work is being conducted by the Ministry of Transport (MOT) that has direct bearing on energy efficiency in the transport sector. It includes the National Land Transport Strategy, the Vehicle Fleet Strategy, Vehicle Emission Testing and the Land Transport Pricing Study.

The National Land Transport Strategy (NLTS)

The NLTS is being developed to establish measurable goals for the land transport system in accordance with the overall mission of "a safe sustainable transport system at reasonable cost". Goals will explicitly relate to environmental and energy efficiency outcomes. It is proposed that the NLTS will become legally binding on local government agencies involved in the transport area and will provide direction for Regional Land Transport Strategies. A NLTS draft report was due by the end of 1995.

Vehicle Fleet Strategy (VFS)

The VFS aims to improve the environmental safety performance of passenger vehicles in a cost-effective, sustainable way by:

- improving air quality by reducing vehicle emissions;
- improving the economic efficiency of the vehicle fleet by:

— improving fuel consumption;

— minimizing travel time in the interests of the individual motorist and the wider economy;

— ensuring that the land transport sector plays its part in meeting New Zealand's commitment to reducing net CO_2 emissions;

— removing impediments and disincentives to the adoption of urban forms and work patterns that minimise travel; and

— providing the context and guiding policy for Regional Land Transport Strategies.

A draft VFS is expected to be presented to the Minister of Transport by the end of 1995. Following public consultation, Cabinet decisions are expected by mid-1996.

Vehicle Emission Testing (VET)

Investigations into possible VET regimes are being contracted to feed into the development of the VFS. A preliminary report on the potential for vehicle emission testing in New Zealand has been prepared (Waring, 1995).

Land Transport Pricing Study: Environment Externalities

This major project aims to quantify transport sector externalities in both physical and monetary terms, and to evaluate possible classes of policy instruments (e.g. pricing, regulations) to reduce significant environmental impacts. This work is expected to be completed during 1996. It will contribute directly to the NLTS.

There are other related land transport pricing studies that address the basis for road user charges and examine safety externalities. The objectives appear to be to ascertain whether all road users pay their correct share and full costs of road transport. The results may have implications for travel demand if implementation is politically feasible.

Other Ministry of Transport Initiatives

The MOT is conducting a range of other investigations that will feed into policy development and will ultimately have some impact on fuel price and modal choice. For example, public transport funding is under review.

Ministry of Commerce

A key responsibility of the Ministry of Commerce is the monitoring of legislative frameworks to ensure markets (including those for transport fuels) operate fairly and efficiently. The Ministry has also been given responsibility for voluntary agreements (VAs) for industry CO_2 reductions (as part of a package of measures to address FCCC obligations) and to negotiate specific agreements with large emitters, industry sectors, etc. The Ministry is exploring the scope for VAs with major transport sector players.

Ministry for the Environment

The Ministry for the Environment (MfE) has several areas of responsibility related to transport energy use. Arguably the most significant are its climate change policy tasks and its role in advising on air quality standards.

Climate Change

The MfE maintains a watching brief on the implementation of policy to address CO_2 reductions in terms of government's policy targets *vis a vis* FCCC obligations.

The MfE is investigating the need to develop measures to limit greenhouse gas emissions other than CO_2 (the transport sector contributes over 65% of New Zealand's nitrous oxide emissions from fuel combustion).

Air Quality

The MfE established ambient air guidelines in July 1994. These contain standards for eight substances that should not be exceeded if human health is to be protected. Recent regional council surveys indicate that levels of carbon monoxide in the vicinity of roads regularly exceeded the ambient guidelines. The MfE has proposed a 10-city survey of CO levels to confirm the problem. Mandatory vehicle testing is a potential outcome of this issue.

Energy Efficiency and Conservation Authority (EECA)

EECA is responsible for advising the government on energy use matters and promoting energy efficiency to all sectors. It has developed and integrated strategy for energy efficiency and is implementing the components of the strategy for which funding is available. The main focus of EECA appears to be industrial energy use, as this is an area where considerable efficiency gains can be made and where stakeholders can be motivated to save costs. Nonetheless, EECA has a number of policy, technical, advisory and communication initiatives aimed at the transport sector (*Energy-Wise News*, 1994):

- advice to local government on transport policy development and implementation through planning documents and strategies;
- advice to central Government on public policy related to transport energy efficiency and related environmental policies and programmes;
- technical advisory services: consultancy advice on fleet management practices and alternative fuels;
- demonstration projects: dissemination of experience gained from local and overseas transport and alternative fuel demonstration projects;
- vehicle emission testing: EECA is working with the Ministry of Transport on applying a VET regime nationally (see Waring, 1995);
- public sector programmes: for example, the Crown Loan Scheme which can provide interest free loans to public agencies for such capital improvements to vehicle fleet efficiency as conversions to alternative fuels;
- energy use monitoring: reports have been commissioned and databases are being established to monitor trends in transport sector fuel efficiency; and
- information services: publications such as "Economic Motoring" and specific articles for the news media are targeted at private motorists.

Land Transport Safety Authority (LTSA)

The LTSA has as an objective to "undertake activities that promote safety in land transport at reasonable cost". LTSA interprets "safety" widely to include environmental safety. This is reflected in their recent "Environmental Focus" discussion document, which proposes a significant commitment to energy efficiency. The core activities of the LTSA are:

- setting safety standards (e.g. Vehicle Inspection Certification), monitoring compliance and investigating accidents;
- provision of safety information and advice; and
- administration of the Land Transport Fund, road user charges and the motor vehicle registration systems.

Practical involvement of the LTSA in energy efficiency issues is most likely through any vehicle emissions testing regime. The LTSA could also encourage use of alternative modes of transport by facilitating safe cycleways and walkways. Another possible avenue is through using part of the driving licence curriculum and test to foster the development of energy efficient driving skills (which are, coincidentally, safe driving skills).

Transit NZ and Transport Network Funding

Transit New Zealand's primary function is to support the development of a safe and efficient land transport system by allocating funds from the Land Transport Fund under the terms of a National Land Transport Programme, which it prepares for government approval. Moves have been made to have project evaluation criteria cover specific consideration of the CO_2 impacts.

New proposals have been put forward for land transport funding and administration in the Land Transport Law Reform Bill that will be considered by Parliament during 1995. The Bill proposes that the regional petrol tax be put on a permanent footing. Funding for public transport will be kept at current levels for two years pending the outcome of the Land Transport Pricing Study.

A dedicated National Road Fund would be established to replace the existing Land Transport Fund. The main advantage of this move is that growth in road user charges will now be directly reflected in the funding available for the provision of land transport infrastructure. Arguably, this could facilitate greater growth in car use. On the other hand, the more flexible funding arrangement could lead to roading investments, such as super highways for trucks (Chapter 7) that might improve fuel efficiency of road transport.

The Bill also proposes changes to how road funds are administered. The motivation for these changes appears to be better economic efficiency, administrative accountability and equity. The energy use implications are not clear.

Local Government

Each regional council is required to produce its own Regional Land Transport Strategy (RLTS), which is required to be "not inconsistent with" the Regional Policy Statement, which prepared under the Resource Management Act. Energy efficiency and CO_2 considerations are often major themes in these regional strategies. These regional documents are binding on district councils.

A draft RLTS is prepared via a regional land transport committee, which receives input from district authorities and other interested committees.

If the necessary legislation is passed, the local and regional government transport planning system will work under guidance provided by the Ministry of Transport in the form of a National Land Transport Strategy.

Consumers

Major consumer interests are represented by the Automobile Association (with 720,000 members), the Consumers Institute and industry groups such as the New Zealand Manufacturers Federation, and large companies, which operate their own vehicle fleets. These organisations do not have public policy responsibilities as such but have an important role to play in providing advice, communicating with their members, etc.

8.3 Selected Policy Measures

Cars and light passenger vans account for around 60% of road transport fuel use. Arguably the most important transport energy goal at the moment is to get people to purchase efficient cars, drive them properly and be more discerning over when and where they use them. Policies aimed at the latter may have a spin-off effect for public transport. This section and reviews a number of car-oriented policy measures that have been seriously investigated for adoption in New Zealand, are under consideration or are in use overseas:

- consumer information, e.g. vehicle fuel economy labelling;
- emission testing to detect gross emitters;
- speed limits and enforcement;
- voluntary agreements with manufacturers and fleet operators;
- mandated fleet weighted standards;
- zero emission vehicle mandates;
- taxes and feebate schemes for vehicles;
- alternative fuels promotion; and
- fuel price increases, carbon taxes.

One of the consequences of a decision to purchase a motor vehicle is the need to fuel the vehicle over its full life cycle, which, for a car in New Zealand, is likely to be 20 years, a lifetime travel of 200,000 kilometres and 20,000 litres of petrol. Consequently, any regulatory or tax measures that influence the purchasing decision towards more fuel efficient vehicles offer the prospect of building improved fuel economy into the national vehicle fleet over the medium- to long-term. Mandatory fuel economy testing and labelling of new vehicles so that this information is available to the purchaser is a possible regulatory measure that could be introduced. Fee and rebate schemes and promotion of alternative fuels are other possibilities.

Once on the road, mandatory testing of vehicle emissions for out-of-tune conditions may be another avenue for improving energy efficiency. At present, the warrant of fitness tests concentrate on ensuring that vehicles reach a minimum level of safety while their state of tune and other aspects that could affect energy efficiency are not given any emphasis. Additional driver education and speed limit enforcement may also save fuel and improve road safety.

The most direct method of signalling to the public the importance of energy efficiency is through the market price of transport fuels. While there is already a considerable tax component in the petrol price, pump prices of fuels in New Zealand are not high by comparison with some other parts of the developed world, notably Europe.

The main lesson from overseas experience with transport policy measures is that the best result will occur when market-based solutions such as pricing strategies are linked to regulatory approaches and education and information programmes.

Consumer Information — Vehicle Fuel Economy Labelling

Education programmes to encourage people to consider fuel efficiency when making vehicle purchase decisions will not be fully effective unless information on relative fuel economy is available. Some manufacturers already supply this data for their vehicles, but consumers will rightly expect information from an authoritative source using a standard method.

Government could support education programmes by requiring mandatory labelling of vehicles according to their fuel economy, as measured over a standard test cycle. A study for the Ministry for the Environment (Beca Carter, 1993) considered the possibility of reintroducing such a scheme, which was tried in the 1980s as a voluntary scheme but failed through lack of industry support and, ultimately, loss of interest by the government. To be effective, it appears that a labelling scheme would need to be mandatory. An alternative to a labelling scheme is provision of new car buyer guides that list the fuel efficiency of different vehicles. Such guides are available in Australia.

The evidence from overseas is that promotional programmes on their own may stimulate some car purchasers into buying a more fuel efficient vehicle, but the effects are not large. Nevertheless, the New Zealand review mentioned above concluded that such a scheme, given a supportive framework of government promotion of energy efficiency and conservation, would show fuel savings that would marginally outweigh the costs of introduction.

It should be noted that information on new vehicle fuel efficiency is a prerequisite for many other potential transport policies, such as fee-rebate schemes, fleet-weighted standards and voluntary agreements. Fuel efficiency data is also important for tracking changes in new car sales over time and for monitoring the effects of policy measures.

In large overseas markets, the issue of obtaining fuel economy figures for all new vehicles sold has been largely resolved. In New Zealand, providing supportable test results for a sufficiently large proportion of the market would be expensive and difficult for the following reasons:

- there are a relatively small number of each vehicle model;
- hundreds of different models from many countries, including used imports; and
- vehicle specifications differ from country of origin where test results are available.

One issue is the difficult question of that test cycle to use (the previous voluntary scheme used the ECE15 cycle, but this is singularly unlike New Zealand vehicle duty patterns). One option is to develop a New Zealand drive cycle, but that would require all vehicles to be specially tested to that cycle. Alternatively, an overseas cycle that approximates New Zealand conditions could be adopted. An Australian cycle, for example, may suffice.

An issue that would need to be examined is whether the relative ranking of vehicles indicated by an overseas drive cycle would change if they were tested under representative New Zealand conditions. It may be that the ranking (as opposed to absolute figures) is not sensitive to which one of several comparable cycles were used. It may also be possible to develop a correction factor to put data from different sources onto a common footing. Either of these possibilities could alleviate the problem that New Zealand faces because it obtains small numbers of vehicles from diverse sources.

Emission Testing — Super Emitters

The level of pollutants from cars can increase markedly as the vehicle ages. Super emitters are those 10% or so of cars and light trucks, usually old or poorly maintained, that typically account for over 50% of emissions. Another 20% to 30% of cars at any time may also be creating pollution in excess of new car standards. In 1993, a major survey in Christchurch, a city with air quality problems, found that 34% of cars were causing excessive pollution (Canterbury Regional Council, 1993). A recent short-term survey by the Consumers Institute in Lower Hutt using a roadside sensor indicated that 41% of vehicles were causing excessive pollution (Consumer, 1995). Two of the major local pollutants are CO and unburnt hydrocarbons. Both are indicative of inefficient combustion and wasted fuel. Keeping a vehicle in a good state of tune helps it to run efficiently and cleanly.

Government influence over vehicle maintenance is exercised through the six-monthly warrant of fitness inspections (WOF) and vehicle inspection certificates (VIC). Some of the deficiencies identified in these inspections have fuel efficiency impacts, but the state of tune of the vehicle and general condition of the fuel/ engine system is not checked. In the past, it has been suggested that emissions testing should be included as part of the WOF, and NZERDC Report 27 estimated that a 1% fuel saving could result. This suggestion was not taken up, possibly because the net benefits were not great enough (only some cars need tuning at the time of testing and hence derive a benefit). In light of local pollution concerns and the Canterbury Regional Council's survey, the issue of mandatory vehicle testing is being revisited. As mentioned earlier, the Ministry of Transport is currently investigating the potential application of a vehicle emission testing regime for New Zealand.

With the development of sophisticated engine management systems, which tend to keep vehicles in a good state of tune for long periods, the benefits of universal emissions testing may be even less than in the past. Mandatory testing of wheel alignment (and driver checking of tyre inflation) could be as, or more, important. One approach that has been suggested in the US is to use a roadside sensor linked to a camera. Passing super-emitters would be detected and photographed. A notice would be sent to the driver to bring the vehicle to a sophisticated central testing station for confirmation that tuning was needed. A penalty would be enforced if the vehicle was not subsequently returned to the station or did not pass the test within a specified period.

This suggestion targets super emitters and avoids the need for many service stations to have sophisticated testing equipment. It could even be extended to service station forecourts where people who pull in for refuelling could be advised of the need for tuning when paying for petrol. This system avoids problems with roadside sensing, such as the results depending on whether the vehicle is accelerating compared with travelling at a steady speed.

Speed Limits and Enforcement

To improve fuel efficiency, similar changes in driving habits are required to those needed for safer and more considerate driving. Consequently, measures introduced on safety grounds, which generally have a much higher public priority than fuel consumption, carry with them the promise of improved fuel economy. There is, in fact, considerable merit in co-ordinating such programmes.

Control of vehicle speeds on the open road is a prime example of where fuel economy and safety are closely linked. The choice of a maximum speed limit is one that has been reviewed from time to time in New Zealand on both accounts. During the "energy crisis", the open road limit was 80 km/h, which is low by international standards. The limit was raised to 100 km/h, reflecting the widespread disregard for the lower limit and the general consensus of the driving public that the old limit was unduly low. This implies some form of implicit trade-off between the increased risk of accidents, the practicalities and integrity of the enforcement effort, the fuel consumption penalty and the value of the saved travel time.

While a reduction back to 80 km/h would bring fuel saving and safety benefits if it were observed, such a reduction is unlikely to receive public acceptance and would be difficult to police. What is more practical is to reduce the degree of speeding, that is the number of drivers travelling much faster than the speed limit. This appears to be one of the goals of the speed camera campaign.

While excessive speed is a safety and fuel efficiency issue, so is travelling too slowly on the open road. New Zealand highways are often used for short local journeys and some drivers do not appreciate the need to accelerate quickly into traffic and then to travel at around the average speed of surrounding vehicles. While this may mean more fuel consumed (compared with sedate driving) for one car it means more economical and safer driving for the majority. Sudden speed braking and subsequent overtaking manoeuvres for the bulk of the traffic stream are avoided.

Physical control of maximum speed through speed-limiting devices, such as are now compulsory on heavy trucks and buses in Europe and are being introduced to Australia, is becoming more accepted by the heavy transport industry. There is also the advisory audible warning device such as are customarily fitted to cars in Japan, a large number of which are imported to New Zealand (where the devices are often disconnected).

NZERDC Report No. 27 estimated that a reduction in the open road speed limit of 10 km/h would save 0.2% of domestic transport fuel, assuming that only 25% of drivers would be susceptible to behaviour modification. Since the time of that report, speeds on New Zealand roads have been progressively increasing. At the same time, of course, the aerodynamic design of cars has also improved so the net effect on fuel consumption may not be significant. Collins (1993) notes that the target set in the National Road Safety Plan of a 1% reduction in average speeds over three years and the longer term targets in the plan may eventually result in a fuel reduction of 5% per annum (assuming the use of speed cameras and a higher level of enforcement). It is conceivable that a 1.5% saving in overall fuel consumption could be made if mean speeds dropped back to the limit of 100 km/h.

Industrial Research Ltd. has found that for most drivers, use of a vehicle fitted with maximum speed control will save around 15% of fuel used in open highway driving. At present, the public acceptance of speed limiting devices would probably be restricted to heavy trucks and, possibly, to coaches. Introduction of physical speed limiting devices into the light vehicle fleet is a matter more of political judgement and public acceptability than one of technology development.

Voluntary Agreements

Given the New Zealand government's policy on voluntary agreements with industry to secure CO_2 emission reductions, it is timely to look at experience with voluntary agreements with vehicle manufacturers and fleet operators. In the past, many countries have adopted voluntary fuel economy targets for their vehicle industries. The only country that has adopted a mandatory target was the US, where the Corporate Average Fuel Economy (CAFE) regulation, which was passed in 1975, set a timetable for the introduction of more efficient cars from 1979.

In the late 1970s, European car manufacturers reached a voluntary agreement whereby the industry agreed to improve fuel economy by 19% between 1978 and 1985. It has been argued that the industry agreed to a target it knew it could easily meet and that, consequently, there was no technological forcing effect. Improvements actually exceeded 20%, and some analysts consider that market forces during periods of high fuel prices had the major effect on manufacturers. In 1991, the European motor industry committed itself to reducing CO_2 emissions by 10% over the period 1993 to year 2005.

In the New Zealand context, it will be difficult to obtain and monitor similar agreements. New cars (or assembly kits) and secondhand Japanese imports are brought into the country by a large number of independent agents. Unlike Europe, a handful of local manufacturers do not dominate the market. There will be strong free-rider incentives in New Zealand. A variation on the tradeable credit scheme mentioned below could be administered by the motor vehicle supply industry as a means to reduce free-riding. As mentioned earlier, a technical prerequisite for voluntary agreements is fuel consumption data for each vehicle sold.

Another approach that has better prospects for success in New Zealand is the use of voluntary agreements with fleet operators. This does not require a standardized fuel consumption test. Instead, fleet operators would monitor actual fuel use and try to lower either absolute fuel consumption or specific fuel demand (e.g. litres per tonne-km or passenger-km). In line with Government policy on climate change, the Ministry of

Commerce is exploring the scope for including vehicle fuel consumption as part of voluntary agreements with industries that have some control over transport operations (e.g. a forestry operation).

Mandated Fleet Weighted Standards (CAFE)

The US government imposed a mandatory Corporate Average Fuel Economy (CAFE) standard on the motor industry, requiring the sales-weighted economy of vehicles measured by the Federal Test Procedure to reduce to certain levels at specific years, or else face large fines. This scheme was born in an situation where US cars were particularly fuel-inefficient (the price of gasoline in the US being one of the lowest in the world), and one where there was already a test procedure in place for emissions control. With its very large market and a large home manufacturing industry, the US was in a better position to introduce such a scheme than New Zealand is now.

The CAFE scheme has experienced strong political opposition over the years, even though its targets have not been particularly onerous. It raised equity issues that relate to manufacturers/importers of mainly small cars (from Japan) and manufacturers of large vehicles. The effect of the CAFE standards has been debated with manufacturers who claim that the changes would have occurred anyway due to fuel price rises, while others maintain that the standards were the main driving force (US cars have nearly the same fuel economy as cars in Europe, where no CAFE standards apply, even though fuel prices are several times lower than in Europe).

One perverse effect of CAFE was to increase the market share of light trucks (treated separately to cars) used for private passenger use. Currently, the CAFE standards for cars are stagnant and those for light trucks are barely improving due to virulent opposition of manufacturers. Out of the big three US manufacturers, only Chrysler supports the retention of CAFE standards. The others favour increased fuel prices for promoting more efficient technologies.

The British government has informally submitted a tradeable credits variation of the CAFE system to the European Community for consideration. A manufacturer that exceeds the standards earns credits that can be sold to those that fall short (mainly producers of large cars). In effect, the manufacturer (and consumers) of large vehicles will be forced to subsidise those producing small cars. This system is a market-based version of the fee-rebate scheme discussed below.

Without a domestic car manufacturing industry, a CAFE or tradeable credits system in New Zealand would have to be aimed at vehicle imports. The inequities in the CAFE approach and the potential for a thin market in credits may make a fee-rebate system more practical.

Zero Emission Vehicle Mandates

In 1990, the Californian Air Resources Board, motivated by the need to reduce air pollution, adopted a zero emission vehicle (ZEV) mandate. This required a growing percentage of each major car manufacturers/importers sales in California to be ZEVs. In practical terms, this means all-electric vehicles. Major car makers are those selling over 35,000 vehicles per year in the state. In the year 2003, the definition of major drops to sales of 3000 per year. The ZEV percentage has been set at 2% for 1998, 5% in 2001 and 10% in 2003. The Californian ZEV mandate has since been adopted by New York and Massachusetts and is being seriously considered by a number of other states.

While the ZEV mandate is aimed at mitigating air pollution, it has a number of implications for energy efficiency. The mandate will spur R&D into electric vehicles, probably resulting in lighter batteries or energy storage, partial solar charging, and efficient regenerative braking. These improvements will produce a vehicle that requires less electrical energy per person-km. Widespread use of ZEVs could also encourage the development of more efficient energy generation systems.

A legitimate issue with ZEVs is the source of the electrical power. Even if this is from fossil-fuelled thermal power stations, a gas combined cycle plant for example, the ZEV energy conversion pathway may be more energy efficient than burning petrol or diesel in car engines. Furthermore, the widespread use of ZEVs will increase electricity demand. With the right economic framework in place, it is quite conceivable that this power could be provided by very efficient power plants, such as fuel cells, or from renewable sources, such as combustion of biomass.

The prime motivation for ZEVs in a country like New Zealand is likely to be reductions in CO_2 emissions rather than widespread and serious air pollution problems. Reforms of the electricity industry in New Zealand, combined with new technology advances in electrical metering, opens up the possibility of ZEVs charging from renewable energy sources. It is conceivable, for example, that a windfarm is built and its output marketed as a ZEV fuel, possibly at a premium over the cost of normal electricity supplies (market research by EECA shows a consumer willingness to pay extra for "green" electricity). The electric vehicles using such an energy supply would be truly ZEVs and the total system would be very efficient at all steps in the energy conversion pathway from generation to end use.

Taxes and Feebate Schemes for Vehicles

The government is able to exercise considerable influence, should it so choose, over the vehicles that are sold on the new and secondhand market in New Zealand. In the past, it did so through a sales tax on new cars, which progressed with engine size. This tax was removed and later replaced with flat rate GST. As larger vehicles tend to be higher priced, there is still some progression in the tax paid against fuel consumption. Government can also deter vehicle purchase by imposing restrictions on hire purchase agreements, again a method once used in New Zealand.

Many overseas governments have introduced and still maintain a progressive duty or tax of this nature, although the reasons for doing so are not entirely related to fuel economy. In some cases, the tax serves to deter foreign exchange expenditure or to tax luxury items. A progressive duty based on engine size can have a distorting effect on demand as there are often good reasons why a larger vehicle is needed for its intended duty. In addition, engine size is not a precise proxy for fuel economy; in fact, kerb weight would be more appropriate, although harder to administer.

Some tax methods aimed to constrain new vehicle purchase could have the contradictory effect of slowing the progress of innovative new technology into the fleet, and can, for this reason, be quite counterproductive. Two policies have been proposed to mitigate this problem. The first is a tax and feebate scheme to differentiate new vehicles and the second is referred to in the US as the "cash for clunkers" programme.

A gas guzzler tax was introduced in the US in 1980 to discourage people from buying very inefficient vehicles. It is a progressive tax, starting with cars having a fuel consumption above 10.5 *l*/100 km. Some analysts believe this tax has encouraged manufacturers to design vehicles to avoid the tax. Another way of stimulating consumer demand for efficient vehicles is to offer a positive tax incentive.

Under the Californian DRIVE+ proposal, sales surcharges on vehicles with high emissions (including CO_2) would pay for a tax deduction on more efficient vehicles (and the costs of administering the scheme). A national version of DRIVE+, known as the "gas guzzler: gas sipper" scheme has been proposed. The essential prerequisite for such fee-rebate schemes is information on new and imported secondhand vehicle fuel efficiency. The second important set of data is likely consumer response (or vehicle marketing response) to different fee-rebate levels (this response could be established by trial and error). With at least the fuel efficiency data and sales monitoring, it appears that an effective fee-rebate scheme could be developed.

"Cash for clunkers" is a programme endorsed in the US 1990 Clean Air Act and is aimed at getting the super emitters off the road. It provides one alternative to emission testing. A cash payment would be offered to a person junking a vehicle older than a specified model year. In one version of the scheme, the cash would come from a company looking for pollution credits. The company may be operating a facility, such as a power station, that is required to reduce emissions or purchase credits.

In principle, cash for clunkers is an economically attractive idea and is strongly supported by vehicle manufacturers. In practice, it is fraught with difficulties. It is difficult to screen out old vehicles that are not super emitters and those that were going to be scrapped regardless. Pilot programmes have been conducted in Delaware, Illinois and Los Angeles, but due to a range of uncertainties, a definitive evaluation of their effectiveness is not possible (Sperling, 1995).

Alternative Fuels Promotion

Financial incentives could be given to manufacturers along the lines of the American Alternative Fuels Act, which rewards manufacturers for producing vehicles capable of running on natural gas, pure alcohol or a mixture of alcohol and petrol. In New Zealand, the incentive could be passed directly to consumers with a fee-rebate system rewarding purchase of vehicles that could run on LPG and CNG. Alternatively, or to reinforce a fee-rebate scheme, the price of LPG and CNG could be lowered by rearranging the taxes on motor fuels to recognise the environmental advantages of these alternative fuels.

Greater use of CNG and LPG offers a wide range of strategic advantages. Firstly, existing vehicles can be retrofitted so that the use of alternative fuels does not depend on influencing new vehicles. While the CNG industry has declined in recent years, there is still a core of installation and engine maintenance skills and a reasonably extensive refuelling network. A good infrastructure is available for LPG in both islands.

Compared with petrol engines, CNG will create 20% to 25% less CO_2 emissions. The savings with LPG can be expected to be around 10% to over 15%. By equipping engines with microprocessor-controlled fuel systems, the CO_2 savings can be maximised and stringent local pollution requirements can also be met. Studies have shown that while energy consumption can rise when heavy diesel vehicles change to CNG (because the efficiency drops slightly), the tailpipe (and total fuel cycle emissions) can fall by 5% to 15% due to the lower carbon content of CNG.

Higher savings may be possible if the engine is optimised and committed to gas use during the original manufacturing process. For this reason it would be advantageous to encourage the installation of alternative fuel systems as original equipment of manufacture (OEM), especially for high mileage vehicles.

While alternative fuel use is expanding overseas, in New Zealand the automotive LPG industry no longer appears to be growing, while the CNG industry is struggling. If this situation continues and the number of alternative fuel vehicles declines over the next five years, then the transport sector will find it even more difficult to contribute to the government's carbon dioxide policy target. Based on past experience, LPG and CNG conversion rates of 20,000 to 30,000 vehicles per year (for each fuel) are feasible.

A positive policy towards alternative fuels would help to retain the existing number of vehicles able to use CNG and LPG. Furthermore, a very useful LPG and CNG conversion rate could be re-established if the taxes on transport fuels were adjusted to reflect the environmental advantages of the alternative fuels and if there was a widespread political commitment to the adjustment for at least ten years.

Fuel Price Increases

It is often remarked that people would drive less if petrol or diesel were more expensive. Governments could alter the price of transport fuels by increasing taxes or pollution levies. In New Zealand, taxes on petrol and diesel are used for general revenue raising and to recover road system costs. The tax/user charge component of the retail price of fuel in New Zealand is moderate by world standards, although this may not always seem the case to the consumer. Figure 8.2 shows the price of fuel and the tax component for a number of OECD countries (IEA/OECD, 1991).

The case for imposing a further tax over and above those mentioned would have to lie in the argument that the market price of fuel does not reflect its true cost to society, possibly because of global atmospheric effects, local air pollution, congestion and loss of land to cars, or other resource depletion issues. The bases for externality levies are not clear cut and are under investigation as part of the Land Transport Pricing Study mentioned above.

A major study conducted as part of a recent Royal Commission enquiry in Great Britain (Royal Commission, 1994) concluded that the cost of air pollution, noise and vibration and climate change risk was between GB£4.6 billion and GB£12.9 billion per annum. The climate change component of these costs was between GB£1.8 and GB£3.6 billion. These costs were derived from a range of estimates of the potential economic effects of climate change expressed in terms of future GDP impacts. To put the estimates in perspective, the total cost of road accidents in Great Britain was assessed at GB£5.4 billion per year and the road building and maintenance costs were nearly GB£7 billion per annum.

Cars and light goods vehicles were considered by the Royal Commission to create 75% of the combined environmental costs. The contribution of heavy goods vehicles, the next major category contributed around 20% to the total.

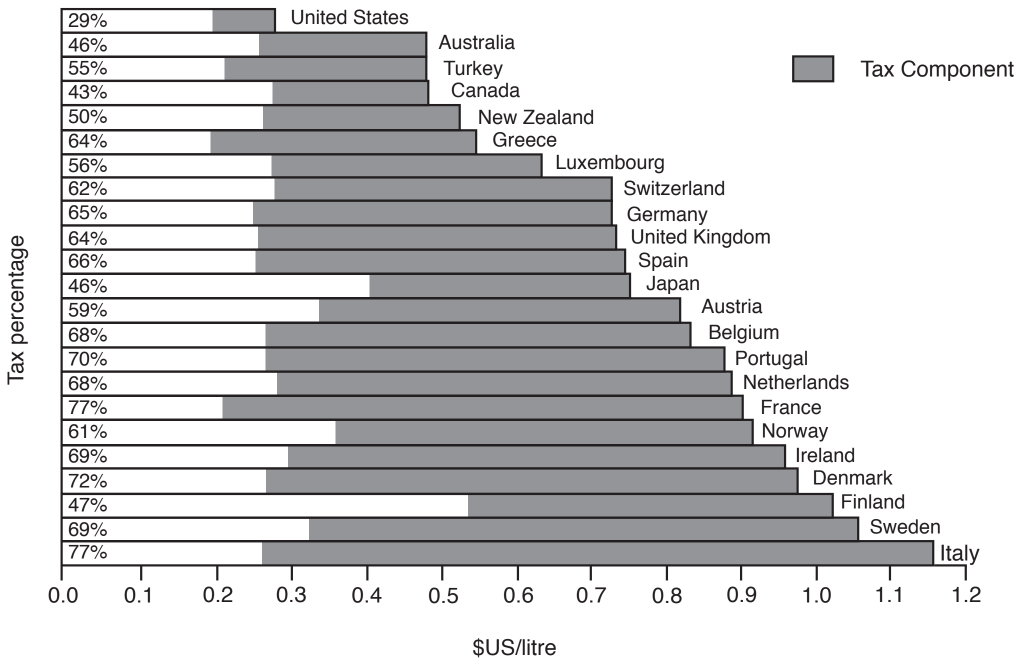


Figure 8.2: OECD petrol prices and taxes 1990 (note: New Zealand has relatively low petrol taxes and prices)

The costs of noise and air pollution depend on local conditions. The climate change costs estimated for Britain may have some relevance for New Zealand. The total number of passenger kilometres travelled in Britain is approximately 600 billion. Using some arithmetic and a few simplifying assumptions indicates that the lower climate change cost estimate for Britain (GB£1.8 billion) translates into a fuel levy of 10 to 20 New Zealand cents per litre.

From several studies carried out in New Zealand (and a large number overseas) it is known that the demand for petrol and diesel fuels is very inelastic in the short run — figures of -0.1 or less have been estimated. A New Zealand study undertaken some time ago (NZERDC, 1977) used this elasticity and concluded that a doubling of the price of petrol would cause an 8% fall in overall transport fuel use, while a 20% fall in consumption would need the price of petrol to be more than trebled.

Some time after a major price increase, demand for transport fuels will become more elastic, as the intervening period allows longer-term changes to take effect. These include vehicle replacement and locational decisions for households and businesses (assuming, of course, that people regard the price changes as permanent). Studies suggest long-run elasticities of -0.2 to -0.3. Even at these elasticities, price increases of around 100% may needed to get a reduction as low as 20% in fuel use.

In other words, consumer behaviour will not respond much to petrol price changes. This is borne out by many other studies. The lack of consumer response could be a reflection of the importance attached to the mobility provided by using petrol; people would rather do without other goods and services than petrol. It may also indicate that many consumers do not perceive many short-term options for reducing consumption. Another likely influence is the relatively small part that the price of petrol plays in the total running costs of a vehicle.

Figure 8.3 shows the costs of running a vehicle for different fuel price levels. While the data is dated, the general distribution has not changed much (Hippel, 1983). The major costs of running a car are fixed and relate to capital purchase, fees, taxes and insurance. For the base vehicle, the average running cost is approximately US 15c/km. A 100% increase in the cost of petrol raises the average running cost to around 17.5 c/km, an increase of only 17%.

Current New Zealand data shows that the relative cost of petrol in this country is even smaller than that shown in Figure 8.3. Recent information on operating costs from the New Zealand Automobile Association for medium-sized vehicles running 12,000 kilometres per year is summarized in Table 8.2 (Automobile

Association, 1995). For a 1601 to 2000 cc vehicle the total cost per kilometre is estimated at 79.9 cents. The largest component of this total is fixed costs, such as depreciation, registration and insurance, which make up 60.4 cents per kilometre. The next largest component is 11.6 cents per kilometre for maintenance, which covers oil, tyres and servicing. The smallest cost is petrol, which for a vehicle with a 8.4 l/100 km fuel consumption, works out at 7.9 cents/kilometre. Doubling the price of petrol only increases total costs by 10%. Figure 8.4 shows the percentage contribution of the three major cost categories to total costs per kilometre for a 1601 to 2000 cc vehicle.

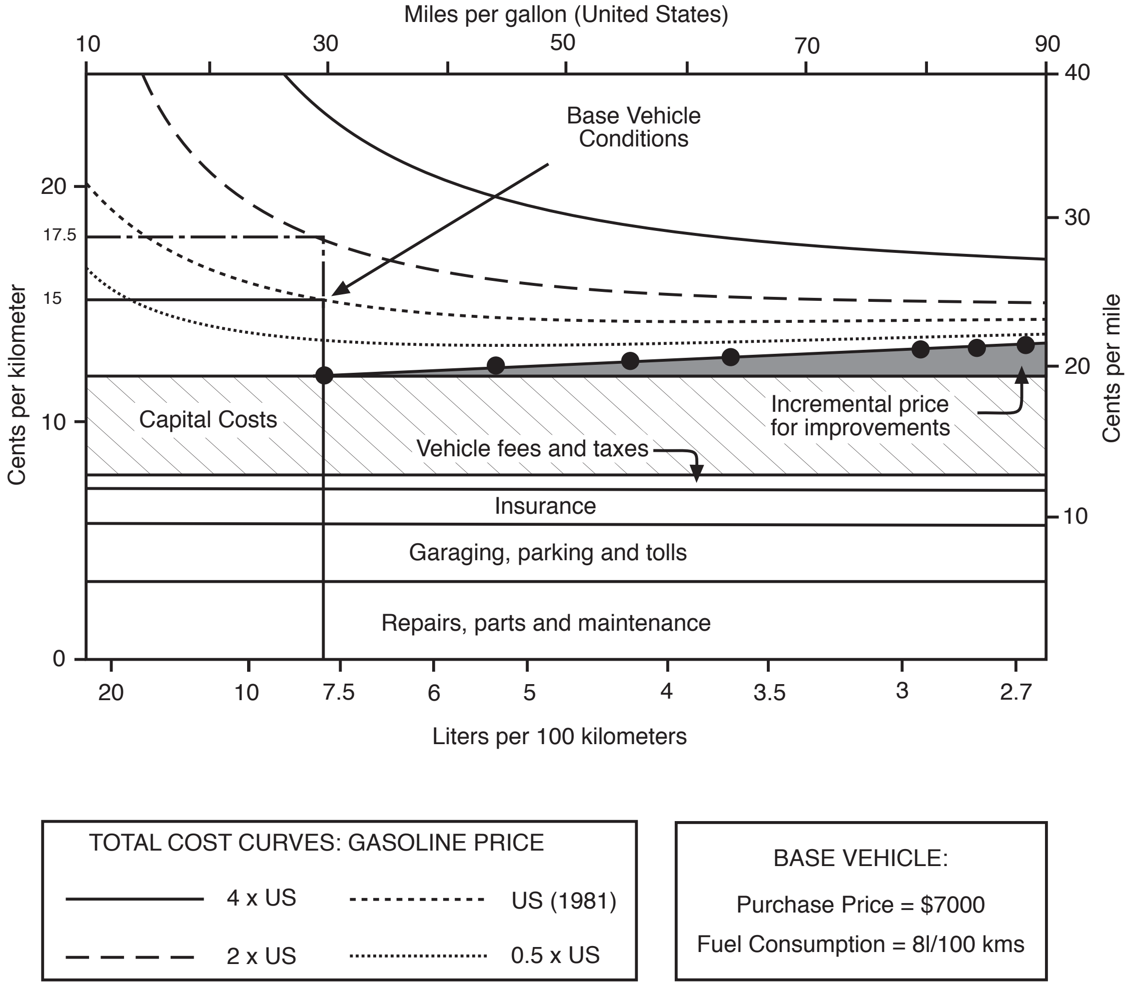


Figure 8.3: Model-based calculation of the impact of improving efficiency, for given base vehicle characteristics

Cost Component	Car Size	
	1300 — 1600 cc	1601 — 2000 cc
Average price	$30,546	$37,779
Fuel efficiency	7.5l/100 km	8.4 l/100km
Fixed costs	49.9 c/km	60.4 c/km
Maintenance	10.4 c/km	11.6 c/km
Petrol	7.0 c/km	7.9 c/km
Total	67.3 c/km	79.9 c/km

Table 8.2: 1995 Car operating costs in New Zealand — 12,000 km/year

This observation, combined with price elasticity-based studies, suggests that it may be more cost-effective to deal with the vehicle technology than trying to induce a response via price rises. An effective policy may be to link the two — use a modest price rise to provide funds for a fee-rebate scheme.

Government has not expressed any overt willingness to use fuel taxation as a tool for influencing fuel efficiency, even though it is the one method that would have minimum distorting effects on the allocation of other resources and one that would encourage efficiency responses from the public and the motor vehicle industry. This is partly explained in terms of the level of increases needed to have an effect on consumption and the political consequences of major tax rises. The fact is that recent governments have, to the contrary, encouraged fuel prices to be driven down by competition as part of inflation management, and this policy enjoys wide public support.

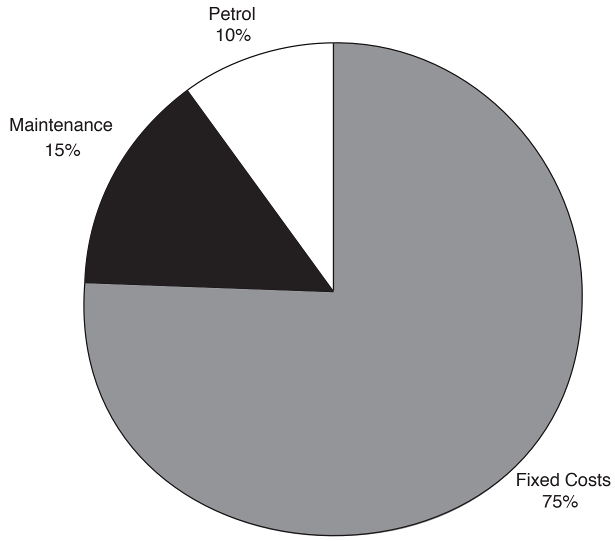


Figure 8.4: Relative importance of different vehicle costs in New Zealand

8.4 Commentary

Two points arise out of Section 8.2. The first is the diffuse nature of responsibilities for transport energy efficiency and the large number of agencies that could affect transport energy use. The second is the relatively long timetable for policy development and the low likelihood that the main policy initiatives will lead to significantly better energy efficiency. Exacerbated by the large number of varied transport end users, these factors mean it will be very difficult for the transport sector to make a pro rata contribution to energy efficiency and emission reductions required under the FCCC by the year 2000.

Society has a range of objectives for transport, the dominant ones being economic efficiency, safety and convenience. The institutional arrangements for transport reflect these priorities. In recent years environmental issues have become more important, but the loss of urban land to motorways and local air pollution seem to be more to the forefront than energy use per se. EECA, an agency with a clear energy efficiency mandate, is a recent arrival on the scene. It is not doing much in the transport area other than trying to work through the Ministry of Transport, which, traditionally, has not had energy efficiency very high on its agenda. In the long term, devices such as the National Land Transport Strategy (NLTS) may provide the level of coordination and focus needed for this diverse sector to achieve greater energy efficiency, without unduly compromising other objectives.

Overall, transport energy policy development is taking place slowly given the need to have some real results within five years. The main policy initiative is the Land Transport Pricing Study. The existence of this study appears to mean that interim or ad hoc decisions that might improve energy use cannot be taken. A likely outcome from the study is an estimate of the amount road users should pay to cover the capital investment in roads as well as maintenance and incremental improvement. An estimate of the externality costs of road transport may also be made.

Presently less than one half of the excise on petrol is spent on land transport, the rest going into the general tax coffers. If petrol was treated the same as any other commodity, the current excise would first be removed and then the user charges and externality costs added on. Adding user charges and externality costs to the price of petrol may not increase the price much (indeed it may fall) if the starting point for petrol and diesel prices is the production and delivery cost of fuel, plus GST, but no other taxes.

Valuing the externality cost of CO_2 emissions is a vexed matter. One approach is to use the cost of avoiding or remedying the emission as a shadow externality value. One of the more cost-effective remedies is tree planting to soak up CO_2. The cost of this remedy has been calculated to be less than 0.5c/litre of petrol if the tree planting occurs in New Zealand (Collins, 1991). This is considerably less than the 10 to 20 cents per litre figure implied by the Royal Commission study in Britain (Royal Commission, 1994). Building in the externality cost of CO_2 alone will probably not dampen petrol consumption. If the other externality costs plus a proper road user charge component increase the price of petrol, then this could dampen consumption. However, the price of petrol, for example, may need to double to have any real effect on consumption (see Section 8.3).

Another policy measure mooted from time to time in New Zealand, and mentioned in Chapter 5, is road pricing based on variable charges for using specific roads at different times of the day. Technology is emerging that could make this a practical proposition. The charge would be aimed at rationing road use by making users aware of the costs they impose on other users by making the road more congested. Such a measure could see people reschedule travel to low-cost periods or shift modes. Either of these actions together with lower congestions, would probably save fuel. There are not many instances where road pricing is warranted, however, so the impact on road transport fuel use overall would not be great.

Road pricing is mentioned at this point because it illustrates the point that policy initiatives aimed at goals other than energy efficiency can impact, either way, on transport energy use. This emphasises the need for a single coordination mechanism, such as the NLTS.

In looking through the list of policies described in Section 8.3, it is evident that some policies would be difficult to apply to New Zealand while others would require a period of research and development. Driver training, as a subset of a speed limits and enforcement measures, could be introduced quickly. There are many ways to expose drivers to training and awareness programmes. The need for training could be linked to demerit points levels, or more strongly emphasised during license testing and so on. Better driving performance alone has the potential to reduce transport energy use by 5% to 10%, although a more realistic expectation at the end of a five year period would be a reduction closer to 3% (enough to meet the government's interpretation of its FCCC obligation).

An emissions testing regime could be introduced fairly quickly if one is warranted. More work is needed to establish the fuel efficiency benefits, especially of a compulsory emissions testing system. This is recognised by the Ministry of Transport, which has a work programme that should deliver recommendations by the end of 1995. A targeted approach, using remote sensing and a few main centre testing facilities, may be the best approach.

Consumers are entitled to new vehicle efficiency data. There will be problems over testing methods and the treatment of imported secondhand vehicles, but these must be resolved quickly. It is difficult to monitor changes in the efficiency of cars entering the fleet for general policy analysis and to test the effectiveness of policies designed to encourage purchase of efficient vehicles without fuel consumption data.

A CAFE-type system, or voluntary agreements on new car average efficiency, would be difficult to administer or agree upon for New Zealand. A fee-rebate system could be introduced on a trial-and-error basis and adjusted on the basis of monitoring information (assuming efficiency data become available). On its own, improving the efficiency of all new cars sold between now and the end of the decade by 10% may cause a fuel reduction of approximately 2.5% (Collins, 1993).

One policy measure that could be adopted immediately and that could affect more than just new cars is alternative fuel promotion. If CNG and LPG conversion rates were restored to historic levels, and cars currently converted were dedicated to alternative fuels, then this measure alone could reduce CO_2 emissions by around 5%. The improvement in fuel use would mirror the emissions reductions, as the latter are due to the lower carbon content of the fuel as well as higher thermodynamic efficiencies. Previous schemes using subsidised loans to encourage conversions need not be revised. Creating an adequate pricing differential between diesel (and, hence, petrol) and LPG or CNG, together with a commitment to retain this for ten years would suffice (GANZ, 1995).

In an economist's ideal world, directly using correct pricing signals would be the sole means to an optimal transport system. In the real world, raising prices is politically difficult and probably impossible if the level being sought was adequate to significantly dampen petrol consumption. A feasible role for petrol pricing involves creating moderate increases by adding small levies to fund transport emission counter-measures. This is, in effect, being done with the regional petrol levy to support public transport. A similar moderate levy could be used to discount the cost of alternative fuels, augment a fee-rebate system, or pay to run a vehicle fuel efficiency testing, information and promotion programme.

In New Zealand there are precedents for such levies on transport fuels, although in the past they were used to fund energy research. Greater awareness now of the need for accountable fund allocation and contestable service delivery should ensure an efficient levy disbursement system.

References

Allan, S (1994). *Opportunities for Energy Efficiency and Conservation through the Resource Management Act and Associated Legislation*, report for EECA, Wellington 1994.

Archer, L J (1992). Exhausting our Options: Fuel Efficient Cars and the Environment, Oxford Institute for Energy Studies, Paper EV14, Oxford, UK.

Armstrong (1983). *The Influence of Cool Engines on Car Fuel Consumption*, Transport and Road Research Laboratory, TRRL Supplementary Report 882, Crowthorne, 1983.

Arnoux and Associates Ltd (1993). *Industry-Government Partnerships for Reducing Net CO_2 Emissions*, February 1993.

Automobile Association (1995). *AA Directions*, Issue No. 19, May 1995.

Automotive Engineering, (1991). SAE, May 1991.

Badwal, S P S et. al. (1990). "Solid oxide fuel cell technology - a potential alternative for power generation", *Greenhouse and Energy*, Swaine, D J (ed.) CSIRO, Australia 1990.

Batts, L A (1981). *Issues in Truck Sizes and Weights,* Technical Report TSW-81-3, Energy and Economics Department, Research and Economic Division, American Trucking Association, Washington DC, USA.

Beca Carter Hollings and Ferner Ltd (1977). *Energy in Transport Volume 1: Data*, New Zealand Energy Research and Development Committee Report 27, November 1977.

Beca Carter Hollings and Ferner Ltd (1977). *Energy in Transport Volume 2: Policies*, New Zealand Energy Research and Development Committee, Report 27, November 1977.

Beca Carter Hollings and Ferner Ltd (1984). *Energy Use and Taxation Policy in the New Zealand Car Fleet*, New Zealand Energy Research and Development Committee, Report 101, February 1984.

Beca Carter Hollings and Ferner Ltd (1986). *Energy Use in Transport - Data Report*, New Zealand Energy Research and Development Committee, Report 131, June 1986.

Beca Carter Hollings and Ferner Ltd (1994). *Changing Energy Efficiency of Petroleum Products in the Transport Sector*, Energy Efficiency and Conservation Authority Report, May 1994.

Beca Carter Hollings and Ferner Ltd and Malcolm Hunt and Associates (1993). *Vehicle Fuel Economy Labelling and Other Fuel Economy Measures,* Report to the Ministry for the Environment, February 1993.

Beng, T S (1991). "Road pricing in Singapore", *Proceedings of the New Zealand Land Transport Symposium 1991*, Transit New Zealand, Wellington.

Blackmore, D R, and A Thomas (eds.) (1977). *Fuel Economy of the Gasoline Engine*, Macmillan, London.

Blakey, S C, R J Saunders, T H Ma and A Chopra (1991). *SAE Paper 910451*, 1991.

Blythe, P T and Hills P J (1991). "The DRIVE project PAMELA - 1. The Technology", *Traff. Eng. and Control V32(5)*, May 1991.

Bone, I H (1994). *Changing Energy Efficiency of Petroleum Products in the Transport Sector,* Beca Carter Hollings and Ferner Ltd report to the Energy Efficiency and Conservation Authority.

Bone, I H (1994). Unpublished estimates, information and opinion based on a variety of information sources, and provided to the Centre for Advanced Engineering.

Bone, I H, Hunt M and Spring C (1993). *Greenhouse Gas Emissions from New Zealand Transport*, BCHF/ Malcolm Hunt Associates, November 1993.

Brennand, A W (1992). "Achieving urban mobility objectives in urban transport", *Summit Proceedings*.

Brotchie, J F et. al. (1990). "Greenhouse implications for urban systems", *Green House and Energy*, D J Swaine (ed.), CSIRO, Melbourne, 1990.

CADDET (1991). *Propeller boss cap with fins (PBCF) allows more efficient ship propulsion*, IEA/OECD publication, Sittard, the Netherlands.

CADDET, IEA/OECD (1991). *Learning From Experiences with Compressed Natural Gas as a Vehicle Fuel*, CADDET Analysis Series No. 5, International Energy Agency/OECD.

CADDET, IEA/OECD (1993). *Fuel Savings using Aerodynamic Styling on Articulated Trucks,* Demonstration Result 129, Netherlands.

CADDET, IEA/OECD (1994). "International solar rally in Australia", *Renewable Energy Newsletter,* Issue 3/94, Harwell, UK.

CADDET (1995). *Renewable Energy Newsletter*, Issue 2/95 (April), IEA/OECD publication, ETSU, Harwell, UK.

Canterbury Regional Council (1993). *Let's Clear the Air — Issues and Options for Air Quality Management in Canterbury and Background Information*, Report 93(35), Canterbury Regional Council.

Cenek, P (1992). "The influence of roads, tyres and aerodynamics on the fuel consumption of commercial vehicles", *Fourth International Heavy Vehicles Seminar*, Auckland.

Clark, R (1991). "Employment, geography and the journey to work: land use, journey to work and passenger transport in two New Zealand Cities", *NZ Transport Symposium.*

Close, W (1991). "Scope for improvements in road freight energy efficiency and road/rail trade-offs", *paper to 1991 National Energy Management Forum*, Melbourne, 1991.

Collins, C (1992). *Recycling Wastepaper and using Virgin Fibre - Comparison of Lifecycle Environmental Impacts*, Report to NZ Pulp and Paper Research Organization, Rotorua.

Collins, C (1991). "Fossil fuel emissions — should polluters pay?", *Terra Nova*, Issue 6, June 1991, Published by Brooker and Friend Ltd, Wellington.

Collins, C (1993). *Transport Energy Management Policies: Potential in New Zealand*, Energy Efficiency and Conservation Authority, Wellington.

Commerce, New Zealand Ministry of, *Energy Data File*, biannual publication.

Commerce, New Zealand Ministry of (1994). *Energy Supply and Demand Scenarios to 2020*, Report prepared with assistance from the New Zealand Institute of Economic Research, Wellington.

Consumer (1995). *Consumer's Institute Magazine*, No. 335, March 1995.

Cotta, A and J H P Van Rens (1983). *Road Transport and Energy*, report by the Netherlands Institute of Transport for the International Road Transport Union and United Nations Economic Commission for Europe, Geneva.

de Beijer, H A and H J W Klein (1993). *SWEAT Thermochemical Heat Pump Storage System, Heat Pumps for Energy Efficiency and Environmental Progress*, J Bosma (ed.), Elsevier Science Publishers, Amsterdam.

Deluchi, M (1991). *Emissions of Greenhouse Gases from the Use of Transportation Fuels and Electricity*, Argonne National Laboratory, Centre for Transportation Research, Argonne, Illinois, 1991, ANL/ESD/TM-22.

Deluchi, M, R Johnston, and D Sperling, (1987). "Transportation fuels and the greenhouse effect", *Transportation Research Record 1175*, pp 33 - 44.

Department of Energy (1990). *Energy Consumption and Conservation Potential: Supporting Analysis for the National Energy Strategy*, Energy Information Administration, US Department of Energy, December 1990.

Department of Transport (1990). *New Car Fuel Consumption: the Official Figures*, HMSO.

Douglass, M and M G Smith (1981). *Urban Transport Fuel Use Evaluation*, New Zealand Energy Research and Development Committee, Report No. 69.

DPIE (1993). *Renewable Energy for Australia*, Department of Primary Industry and Energy, Canberra.

Eden Resources Ltd (1993). *Renewable Energy Options for New Zealand*, report to the Ministry of Commerce, Wellington.

EECA (1995). *Energy-Wise Monitoring Quarterly*, Issue 1, June 1995, Energy Efficiency and Conservation Authority, Wellington.

Energy Authority of New South Wales (1985). *Truck$ave - Bulk Haulage Economy Demonstration*, Sydney.

Energy-Wise News (1994). Issue No. 38, December 1994. Published by EECA, Wellington.

Environment, NZ Ministry of (1994). *Climate Change - The New Zealand Response, New Zealand's First National Communication under the Framework Convention on Climate Change*, Wellington.

Everall, P F (1968). *The Effect of Road and Traffic Conditions on Fuel Consumption*, Road Research Laboratory, Report LR226, Crowthorne, Berkshire.

Fitzsimons, J (1990). "Urban form and transport fuel in Auckland", *NZ Planning Quarterly*.

Frith, W J (1994). "Walking Patterns in New Zealand and their Pedestrian Safety Implications", *Proceedings of IPENZ Annual Conference 1994*.

Fuel Cell Implementation Committee, (1990). *Fuel Cell Program of the Department of Energy, the Gas Research Institute and the Electric Power Research Institute*.

GANZ (1995). *Cleaner Air for New Zealand — Reducing Motor Vehicle Emissions through Alternative Fuels*, Gas Association of New Zealand, Wellington.

Gay, P and D Bugnot. "Real time tire pressure electronic monitoring system with dashboard possibilities", *SAE Paper 890106*.

General Motors (1994). *General Motors 1994 Annual Report - Global Integration, General* Motors Corporation, Detroit.

Glazer, F C (1989). "Ten cities strategy for transportation demand management", *Transportation Research Record*, 1212.

Hagey, G et. al. (1992). "Status of fuel cell systems development/commercialization and future systems energy, environmental and economic benefits", *Proceedings, Sessions I-IV, International Conference - Next Generation Technologies for Efficient Energy End Use and Fuel Switching*, Dortmund, Germany, International Energy Agency.

Harris, G, S Gale, R R Allan, C Lucas and M Marinkovitch (1993). *Promoting the Market for Energy Efficiency*, Report to the Officials Committee on Energy Policy.

Hippel, F von and B G Levi (1983). "Automotive fuel efficiency: the opportunity and weaknesses of existing market incentives", *Resources and Conservation*.

Hoffman and Zimdahl (1991). *Recommended Speed Indication within the Motor Vehicle - a Contribution to Fuel Saving through the Wolfsburg Wave Information System*, University of Berlin and Electronics Research Division VW, reported in "Low Consumption/Low Emission Automobile", *Proceedings of an Expert Panel*, Rome, February 1990.

Hopkins, D (1994). "Smart thermal skins for vehicles", *Science News*, Fall 1994, Lawrence Berkley Laboratory, California.

Huss, Hans-Ulrich (1992). "Keynote address for Session III: Transportation", *Proceedings, Sessions I-IV, International Conference - Next Generation Technologies for Efficient Energy End Use and Fuel Switching*, Dortmund, Germany, International Energy Agency.

IANGV (1994). *The International Association of Natural Gas Vehicles NGV Environmental Position Statement,* International Association for Natural Gas Vehicles.

IEA (1993). *Cars and Climate Change*, IEA, Paris.

IEA/OECD (1991). *Fuel Efficiency of Passenger Cars*, IEA/OECD, Paris

IEA/OECD (1990). "Low consumption/low emission automobile", *Proceedings of an Expert Panel*, Rome.

IEA/OECD (1991). *Fuel Efficiency of Passenger Cars*, Paris.

IEA/OECD (1992). *Cars and Climate Change*, Energy and the Environment Series, OECD, Paris.

Isaacs, N (1993). *New Zealand Energy Research 1970-1993: An Annotated Bibliography*, Centre for Building Research, Victoria University of Wellington, report to EECA, Wellington.

Itoh, T (1992). "Research and development of automotive ceramic gas turbine", *Proceedings Sessions I-IV, International Conference - Next Generation Technologies for Efficient Energy End Use and Fuel Switching*, Dortmund, Germany, International Energy Agency.

Jones, P (1991). "The road pricing debate in Europe and South-East Asia: an update on current issues", *Proceedings of the New Zealand Land Transport Symposium 1991*, Transit New Zealand, Wellington.

King, W (1991). "Turnpike — a New Zealand alternative", *Proceedings of the New Zealand Land Transport Symposium 1991*, Transit New Zealand, Wellington.

Lewis, R G and I Bone (1987). *Fleetsave - Fleet Management Programme and Data Monitoring Programme*, NZERDC Report No. 146.

LFTB (1990). *Final Report of Activities*, Liquid Fuels Trust Board Report LF6020.

LFTB Reports 1022 to 1095. Liquid Fuel Trust Board Reports on Lignites — See Isaacs, 1993.

Lovins A B, J W Barnett and L H Lovins (1993). "Supercars - the coming light vehicle revolution", *1993 Summer Study of the European Council for an Energy-efficient Economy*, Rungstedgard, Denmark.

Martin, D J and R A W Shock (1989). *Energy Use and Energy Efficiency in UK Transport up to the year 2010*, Energy Technology Support Group, Harwell, report to the UK Department of Energy, HMSO.

Mendler, C (1992). "Variable control systems for increasing engine efficiency throughout the full power range", *Proceedings International Conference on Next Generation Technologies for Efficient Energy End Uses and Fuel Switching, Sessions I-IV*, Dortmund, Germany, April 1992, Pub. IEA.

MRL Research Ltd. (1993). *Attitudes Towards Energy Efficiency*, Report to EECA and the NZ Ministry of Commerce, Wellington.

Neumann, K H (1990). "Energy efficiency as a tool for influencing energy technology", in *OECD/IEA Expert Panel on Low Consumption/Low Emission Automobile*, Rome.

Newman, P W G, J R Kenworthy and T J Lyons (1987). *Transport Energy Conservation Policies for Australian Cities,* Environmental Science, Murdock University end of grant report, Project No. 836, for National Energy Research Development and Demonstration Council.

Newman, P W G and J R Kenworthy (1991). *Towards a More Sustainable Canberra*, Murdock University, Western Australia.

Newman, P W G (1991). "Sustainable development and urban planning", *Royal Australian Planning Institute Conference*.

New Zealand Government (1989). *Transit New Zealand Act*.

New Zealand Government (1991). *Resource Management Act*.

Noble J, J West, J B Randle, P D Ritchie and J Owen (1981). *The Feasibility of Electric Vehicles in New Zealand*, LFTB Report LF2009/NZERDC Report 61.

Owens, S. (1985). "Energy demand: links to landuse and forward planning", *Built Environment*, Vol. 11 No 1.

Pharoah, T C and J Russell (1989). *Traffic calming: Policy and evaluations in three European countries*, South Bank Polytechnic, UK.

Phillips, P H (1980). *I'm for 80: An Energy Conservation Experiment on Auckland's Western Motorway*, NZERDC Report No. 43.

Phillips, P (1985). *Impediments to Commuter Vanpooling*, NZERDC Report R118.

Phillips, P H (1989). *Team Tauranga: A Community Based Fuel Conservation Programme*, NZERDC Report No. 89.

Ramshaw, J and T Williams (1981). *The Rolling Resistance of Commercial Vehicle Tyres*, Transport and Road Research Laboratory Report SR701, Crowthorne.

Royal Commission (1994). *Royal Commission on Environmental Pollution, Eighteenth Report — Transport and the Environment*, HMSO, London.

SACTRA, (1994). *Trunk Roads and the Generation of Traffic*, Standing Advisory Committee on Trunk Road Assessment Report, UK Department of Transport.

Sims, R (1993). *Biofuels in Renewable Energy Opportunities for New Zealand*, C Collins (ed.), Ministry of Commerce, Wellington.

Sperling, D (1995). *Future Drive - Electric Vehicles and Sustainable Transportation*, Island Press, Washington, DC.

Steer, Davies and Gleave Consultants (1993). *Assessment of Methods for Funding Public Transport and Restraining Traffic in Wellington*.

Stone, R (1989). *Motor Vehicle Economy*, McMillan Ltd.

Thompson, T (1990). "Road user charging - the current state of technology", *Traff. Eng. and Control*.

Thorpe, N and P Hills (1991). "The DRIVE project PAMELA - 2. The scope of automated pricing systems", *Traff. Eng. and Control*, V32(7/8), July/August 1991.

Transport, U.K. Department of (1991). *New Car Fuel Consumption*, Official Figures of ECE15 Tests.

Transport, NZ Ministry of (1989). *Commercial Road Transport Monitoring Reports, 1986-87 and 1988-89,* (2 volumes), Wellington.

Transport, NZ Ministry of (1995). *Land Transport Pricing Study - National Roading Account: The Cost of Roading Infrastructure*, Wellington.

Travers Morgan (1991). *New Zealand Urban Bus Study Stage 3: Analysis of Public Transport Patronage Trends*, by Travers Morgan (NZ) Ltd for Transit New Zealand, Wellington.

UNEP (1994). *Climate Change and Energy Efficiency in Industry*, United Nations Environment Programme publication.

University of Canterbury (1994). "Sterling Stirling engine", *1994 UC Research*.

Waring, P (1993). Engine prewarming and fuel economy, pers. comm. outlining research undertaken by Industrial Research Ltd for the Foundation for Research, Science and Technology.

Waring, P, R Raine and R Lusby (1995). *Review and Investigation of the Potential of Vehicle Emission Testing for Application in New Zealand*, Report for the Ministry of Transport and EECA, Wellington.

Waters, M H (1990). *UK Road Transport's Contribution to Greenhouse Gases: A Review of TRRL and Other Research*, TRRL Contractor Report CR223.

Waters, M H L (1992). "Road Vehicle Fuel Economy, Transport and Road Research Laboratory", *State-of-the-Art Review 3*, HMSO, London.

Watson, H C and C R Watson (1990). "Near and long term prospects for the reduction in the road transport contribution to greenhouse gases", *Green House and Energy*, D J Swaine (ed.), Pub. CSIRO, Melbourne.

Wellington City Council (1994). *Working Document on Transport Strategy*.

Wellington Regional Council (1992). *GATS Evaluation Stage II. Working Paper. Landuse Impacts of Different Transport Alternatives*. Prepared by Murray-North.

Wellington Regional Council (1992). *Proposed Regional Land Transport Strategy*.

Williams, T, I C P Simmons and D J Jacklin (1981). *Fuel Consumption Testing of Heavy Goods Vehicles*, TRRL Supplementary Report SR 687, Crowthorne.

Winkelhofer, E et. al., (1992). "Combustion control in diesel engines — the basic strategy and the role of fundamental development technologies", *Proceedings, Sessions I-IV, International Conference - Next Generation Technologies for Efficient Energy End Use and Fuel Switching*, Dortmund, Germany, International Energy Agency.

Wood, K (1995). Pers. comm., light rail data provided to the Centre for Advanced Engineering.

Wood, K (1991). "It will revolutionise transport in New Zealand", *Land Transport Symposium*, Transit New Zealand.

Woodhull, J (1992). "Calmer, not faster — a new direction for the streets of Los Angeles, Southern California Rapid Transit", *Transportation Research Record*, 1305.

Works Consultancy Services (1995). *Light Rail Transit Feasibility Study*, contract T/756 completed in association with MVA Consultancy for Wellington City Council and Wellington Regional Council.

Contributing Personnel

Contributing personnel to the Transport Task Group were:

Mr Ian Bone, Beca Carter Hollings and Ferner, Auckland

Mr Mark Galvin, Industrial Research Limited, Lower Hutt

Mr Ian Moncrieff, Liquid Fuels Management Group Limited, Wellington

Mr Tony Brennand, Wellington City Council

Mr Peter Cenek, Works Central Laboratory, Lower Hutt

Ms Christine Perrins, Ministry of Transport, Auckland

Mr Keith Jones, UniServices, University of Auckland

Mr Peter Winder, Auckland Regional Council

Mr Malcom Hunt, Malcom Hunt Associates, Wellington

Index

Index

M

N

O

P

R

S

Energy Efficiency

A Guide to Current and Emerging Technologies

There is growing concern, both in New Zealand and overseas, that the practical application of energy efficiency measures is essential if a reliable energy supply is to be assured in the future. While building new power stations might be seen as one way of mitigating future energy supply vulnerabilities, new technologies in energy efficiency offer at least a partial remedy that should not be ignored.

Energy Efficiency: A Guide to Current and Emerging Technologies is published in two volumes. Volume 1, *Buildings and Transportation*, considers energy efficiency in the areas of Domestic Buildings, Commercial Buildings and Transport. Volume 2, *Industry and Primary Production,* discusses energy efficiency in the context of Primary Production, Food Processing, Forestry Processing, Manufacturing and Minerals and General Industrial Technologies.

The focus is on energy efficient technologies currently available and applied overseas but not widely used in New Zealand, and on emerging technologies that are likely to prove practical for New Zealand use within the next decade. While the emphasis is on New Zealand experience, the technologies discussed have application worldwide. Barriers that might restrict the use of individual technologies are also discussed.

Five international experts on energy efficiency assisted in the production of *Energy Efficiency: A Guide to Current and Emerging Technologies.* They were:

- *Dr. Adam Brown, Manager of the Renewable Energy Department at the Energy Technology Support Unit at Harwell, UK;*
- *Professor Ian Fells, Professor of Energy Conversion at the University of Newcastle-upon-Tyne, UK;*
- *Mr Stephen Selkowitz, Programme Leader of the Building Technologies Programme in the Centre for Building Science at Lawrence Berkeley Laboratory (University of California);*
- *Professor Daniel Sperling, Professor of Environmental Studies and Civil Engineering and founding Director of the Institute of Transportation Studies at the University of California (Davis); and,*
- *Mr Martin Thomas, Principal of Sinclair Knight Merz, Consulting Engineers, Sydney.*

The efficient use of energy resources is a matter of vital importance to New Zealand, and the publication of *Energy Efficiency: A Guide to Current and Emerging Technologies* is a significant step forward in addressing how energy can be used more efficiently in the coming years in all facets of New Zealand life and industry.

CAE Centre for Advanced Engineering
University of Canterbury, Christchurch, New Zealand